BOEING

FedEx Flight 14
MD-11-F, N611FE
Newark, New Jersey
31 July 1997
DCA97MA055

Proposed Findings
Boeing—Long Beach Division

EXECUTIVE SUMMARY

On July 31, 1997, at about 01:32 EST, Federal Express Flight 14, a McDonnell Douglas MD-11-F, Fuselage Number 553, operating on a scheduled cargo flight from Anchorage, Alaska to Newark, New Jersey, was destroyed while attempting to land on runway 22R at Newark. All five people aboard the aircraft (two flight crew, one jump seat rider, and two off-duty FedEx employees) escaped with minor injuries via the captain's clearview window. The aircraft and its cargo were destroyed by impact forces and post-impact fire.

The investigation into the accident revealed that the aircraft's manually-flown approach to runway 22R was stable and on speed until just prior to initial touchdown, at which point the pilot flying (PF) reportedly sensed a last-minute increase in the aircraft's sink rate[1] and initiated a large nose-up elevator input and manually advanced the throttles to near takeoff power. The aircraft touched down and became airborne due to the increased angle of attack and additional power. In an apparent attempt to avoid a tailstrike and to plant the aircraft on the runway so that wheel braking could be initiated (a concern based on runway 22R's relatively short available stopping distance), the PF applied large aircraft nose down (AND) elevator deflections and right wing down (RWD) roll control deflections, and reduced engine power. These actions resulted in the aircraft impacting the runway on the right main landing gear at a flat pitch attitude and at an 8-10° RWD roll attitude, which ultimately led to the separation of the right wing just inboard of the main landing gear attach fitting. The descent rate at the aircraft's center-of-gravity, derived from flight recorder data, combined with the aircraft's RWD roll rate (also derived from flight recorder data), produced a calculated rate of descent at the right main landing gear (RMLG) of 13.5 feet per second (fps) during the second touchdown impact. Additionally, the recorded vertical acceleration at the beginning of the second touchdown impact was only 0.5 g; thus, aircraft weight that would have normally been obviated by 1.0 g wing lift was transmitted directly into the RMLG in addition to the kinetic energy developed from the combined sink and roll rates. The combined potential and kinetic energies dissipated into the RMLG were more than 3 times the RMLG's energy absorption requirements for certification; that is, the energy imposed on the RMLG during second touchdown impact was outside the FAA-certification-defined design envelope by a factor of more than 3.

Simply put, a sink rate of approximately 13.5 fps (11 fps at the center of gravity plus RWD roll rate) at touchdown impact is, by itself, outside the design envelope; a 13.5 fps sink rate landing on a single main landing gear is even

[1] The PF's perceived increased sink rate was not evident in the flight recorder data.

further outside the design envelope; a 13.5 fps sink rate landing on a single main landing gear with a net 0.5 g downward acceleration is yet further outside the design envelope.

Flight recorder data, pilot interviews, and evaluation of the aircraft's non-volatile avionics memory indicated that the aircraft was functioning normally up to the point of second touchdown impact. The only aircraft anomalies noted at the time of landing were: 1) the No. 1 engine thrust reverser was placarded inoperative, and 2) the left landing light had burned out. Laboratory analysis of the wing and landing gear primary fracture surfaces revealed that the failures were the result of ductile overload with no pre-existing conditions noted, and that there were no material or dimensional anomalies in any of the components examined.

Analysis of the physical evidence, ground scars, flight recorder data, and data generated from a computer-based dynamic structural analysis model indicates that the structural failure sequence of the wing began with a nearly instantaneous load into the wing rear spar web from the second touchdown impact. This "punch load" was the result of the second touchdown impact bottoming the RMLG strut and tires, which in turn introduced large loads into the RMLG-to-wing attach fitting. The attach fitting transmitted these loads into the rear spar, resulting in the failure of the rear spar shear web followed by the failure of additional wing box structure (spar caps and covers).

After the aircraft came to rest the first officer attempted to open the R1 door, but it only opened partially. He then tried to get to the L1 door but it was blocked by debris. By that time the captain had opened his clearview window and evacuation was accomplished using the window as the exit.

Boeing Findings are:

1. Aside from the inoperative No. 1 engine thrust reverser and left landing light, the aircraft and its systems were functioning normally at the time of the accident.
2. All observed primary structural failures of the aircraft were the result of ductile overload.
3. The condition and operability of the active and inactive passenger exit doors immediately after the aircraft came to rest, other than the R1 door, is not known.
4. Weather, communications, and air traffic control were not contributing factors.
5. The aircraft's approach to Newark runway 22R was stabilized and on glide path and localizer until just prior to the first touchdown.
6. The accident landing flare was not consistent with Boeing Long Beach Division (BLBD)-recommended and published landing procedures and techniques. A go-around, initiated when the pilot believed that large control deflections and throttle inputs had become necessary just before the first

touchdown, would have been consistent with BLBD-recommended and published procedure.

7. The control inputs recorded just before the first touchdown and between the first touchdown and second touchdown impact were not consistent with FedEx's "High Sink Rate and Bounce Recovery Technique" recommendations.
8. The large pilot-commanded AND elevator control inputs prior to the second touchdown impact, in combination with RWD aileron inputs and power reduction, resulted in a high RMLG sink rate and loads in excess of established design loads which fully compressed (bottomed) the RMLG strut.
9. The large pilot-commanded AND elevator control inputs prior to the second touchdown impact also resulted in a nose-down pitch rate that reduced the aircraft's recorded vertical acceleration from approximately 1.0 g to approximately 0.5 g at second touchdown impact.
10. The decrease in recorded vertical acceleration at the second touchdown impact introduced loads into the RMLG that are normally obviated by 1.0 g wing lift, and that were additive to the loads on the RMLG resulting from the combined sink and roll rates.
11. The bottomed RMLG strut introduced large loads into the landing gear and wing structure that were far in excess of established design loads.
12. The energy introduced into the RMLG at second touchdown impact was greater than FAR 25.723-defined design ultimate conditions by a factor of 3.
13. The aircraft was certified to, and met or exceeded, all applicable FAA requirements.

Boeing Safety Recommendations:

Now that the extensive analysis into identifying the sequence of initial structural failures occurring during the Newark accident is complete, and with consideration given to the Faro DC-10 and JFK L-1011 accidents, Boeing has begun an evaluation into the net safety benefits of installing a vertical fuse on the DC-10 and MD-11 landing gear. The evaluation will require further extensive analysis and research; the results will be provided to the NTSB upon completion. Boeing also intends to continue with its participation in the FAA's review of the landing gear sink rate design requirements, and with the product improvement development of updated FCC software (which has been underway since before this accident—see Section 2.7, second paragraph).

In addition, Boeing suggests the following Safety Recommendations specific to this accident:

1) *Operators should stress to their flight crews the importance of executing a go-around any time below approximately 500 ft. above ground level (AGL) that a stable approach becomes destabilized. As a general "rule of thumb," if large power and/or control deflections are required to maintain the desired flight path and/or alignment with the runway, then a go-around is warranted.*

2) Manufacturers should revise their Maintenance Manual hard landing defining and inspection criteria to include information on the effects of reduced lift and adverse aircraft attitude on loads into the landing gear. Data developed during this investigation show that the absolute recorded vertical acceleration value during landing should not be the only criteria for determining if a hard landing has taken place. The recorded vertical acceleration at the beginning of the touchdown can also be very important. Specifically, if the recorded vertical acceleration at the beginning of the landing is less than 1.0 g, then aircraft weight that is normally accommodated by 1.0 g wing lift is instead transmitted into the landing gear on top of the loads required to decelerate the airplane vertically from the aircraft's sink rate. The effects of non-routine aircraft pitch and roll attitudes on energy introduced into a singular landing gear should also be a part of a hard landing evaluation. For example, nose landing gear-first firm landings, or firm landings in a significant left or right wing down roll attitude or with a rapid roll rate may warrant a hard landing inspection if most of the landing energy absorption is accomplished by one landing gear. Boeing is in the process of revising the MD-11 Maintenance Manual (MM) to incorporate this type of information; once the MD-11 MM is revised, it will be used as the guide for revising the other Boeing MMs.

3) Operators should be made aware of the issues discussed in Recommendation 2 above so that they can more thoroughly evaluate the severity of a hard landing from available data. Boeing is preparing an operator advisory on this subject.

Boeing suggests the following Safety Recommendations generic to landing safety issues:

1. *Tailstrikes, hard landings, hard nose landing gear touchdowns, and other landing difficulties seem to occur on a periodic or cyclical basis. Data shows that increased education and awareness has a strong positive impact on the rate of these incidents and accidents. Operators that haven't done so already should therefore consider developing periodic awareness and training to address landing issues and then ensure that all crew members receive this training.*
2. *Operator management and Air Traffic Control personnel who are not already aware of the safety benefits associated with proactive go-arounds need to be aware of, and endorse, the use of the go-around as an accident avoidance maneuver.*

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1 FACTUAL INFORMATION

1.1 HISTORY OF THE FLIGHT

On July 30, 1997, Federal Express (FedEx) Flight 14, a McDonnell Douglas MD-11-F (Freighter) aircraft, registration number N611FE, departed Anchorage, Alaska at 23:41 Universal Coordinated Time (UTC), on the continuation of a scheduled cargo flight to Newark (originating in Singapore with en route stops at Penang, Taipei, and Anchorage). A crew change was performed at Anchorage for the last leg of the flight to Newark; in addition to the two flight crew there were two off-duty FedEx employee passengers seated in the courier seats aft of the cockpit and a third passenger seated in a cockpit jumpseat. The aircraft departed Anchorage with the No. 1 engine thrust reverser placarded inoperative. The crew noted before departure that the aircraft had three autobrake system entries (system not arming) in the ship's log, which had been signed off as corrected. Because of the autobrake system write-ups, the crew elected to make a maximum-power takeoff at Anchorage (even though the Autobrakes armed properly for takeoff[2]); the departure, en route, and arrival into Newark were unremarkable.[3]

The captain was the flying pilot for the leg into Newark. Flight 14 arrived at the Newark area during nighttime visual meteorological conditions. The left landing light was noted by the crew to be inoperative. Runway 22L, the longer of the parallel runways, was reported closed. Runway 22R was available and the crew planned their arrival for that runway. Useable runway beyond the glideslope intercept point on runway 22R is listed on airport charts[4] as 6860 feet (ft.); when the crew checked their on-board Airport Performance Laptop Computer (APLC) they found that, using MED (Medium) autobrakes, the stopping distance at their landing weight would be 6080 ft.[5] The crew decided to use MAX (Maximum) autobrakes, which lowered the APLC stopping distance to 5100 ft. The crew used V_{REF}+5 Knots for a reference speed of 162 knots with flaps set to 50°.[6] The captain indicated that he intended to land the aircraft at the glideslope intercept point to avoid floating[7] and subsequent loss of available runway for braking.

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[2] Group Chairman's Factual Report Operations /Human Performance Group, Attachment 5A, page 13.
[3] Group Chairman's Factual Report Operations /Human Performance Group, page 4.
[4] Group Chairman's Factual Report Operations /Human Performance Group, Attachment 2, Jeppesen Chart 10-9A
[5] Addendum to the Group Chairman's Factual Report Operations/Human Performance Group
[6] Group Chairman's Factual Report Operations /Human Performance Group, page 5 and Cockpit Voice Recorder transcript page 33.
[7] Group Chairman's Factual Report Operations /Human Performance Group, Attachment 5A page 13.

The captain disconnected the autopilot during the approach and manually flew the aircraft while monitoring localizer and glideslope indications. Autothrottles remained ON, per FedEx policy.[8] The weather was scattered clouds at 8,000 feet with light winds,[9] but ambient conditions were dark due to the early morning hour.

The crew reported that the aircraft started to "settle" at about 20 ft.;[10] the flight data recorder (FDR) indicated no increase in sink rate at that point, but did record an engine power increase and an aircraft nose up (ANU) elevator deflection just before and during the first touchdown on 22R. The FDR data indicate the first touchdown was slightly right wing down (approximately 1°) at about 7.6 feet per second (fps).[11]

The aircraft became airborne after the first touchdown for a period of approximately 3 seconds. The FDR recorded large aircraft nose down (AND) elevator deflections, and right wing down (RWD) aileron and spoiler deflections between the first and second touchdowns. At second touchdown impact, the FDR recorded the aircraft's pitch attitude as 0.7° AND and roll attitude as 9.5° right wing down (RWD); the vertical acceleration recorded at the start of second touchdown impact was approximately 0.5 g, and the maximum recorded vertical acceleration during second touchdown impact was approximately 1.7 g.[12]

Flight recorder data indicate that the RWD roll rate between the first and second touchdowns was arrested by runway contact with the right main landing gear (RMLG) during second touchdown impact, as the aircraft rolled left from 10° RWD to approximately 4° RWD before the recorder "dropped out" for a period of approximately 1.5 seconds.[13] When the FDR data resumed after the drop out, approximately 3 seconds after the second touchdown, the aircraft's recorded roll attitude was approximately 33° RWD.

The right wing of the aircraft separated from the fuselage during the accident sequence, and the aircraft continued rolling to the right, eventually coming to rest inverted and off the right side of the runway.[14] After the aircraft stopped, the first officer went aft to assist the passengers with the evacuation. When he tried to open the right door he heard the pneumatic door actuation bottle blow but the door only opened about an inch. Access to the other door was blocked by debris, and smoke was entering the courier area. The captain was able to open

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[8] Group Chairman's Factual Report Operations /Human Performance Group, page 5.
[9] Group Chairman's Factual Report Operations /Human Performance Group, page 12.
[10] Group Chairman's Factual Report Operations /Human Performance Group, page 5.
[11] Airplane Performance Study, page 2.
[12] Airplane Performance Study, page 3.
[13] A "drop out" is usually the result of an interruption in the data stream from the flight data acquisition unit (FDAU) to the flight recorder.
[14] Structures Group Chairman's Factual Report of Investigation, pp. 2-3.

his sliding side window and the passengers and crew evacuated the aircraft via the opened window, sustaining only minor injuries.[15]

The aircraft was destroyed by impact forces and post-impact fire.

The accident occurred during the hours of darkness at about 01:32 Eastern Standard Time (EST) or 05:32 UTC, on 31 July 1997.

1.2 INJURIES TO PERSONS

The passengers and crew were treated for minor injuries.[16]

1.3 DAMAGE TO AIRCRAFT

The aircraft was destroyed by impact forces and post-impact fire.[17]

1.4 OTHER DAMAGE

The cargo aboard the aircraft was destroyed by fire.[18]

1.5 PERSONNEL INFORMATION

The captain for this flight had accumulated about 11,000 total flight hours, of which about 1,253 were in the MD-11; of his total MD-11 time, approximately 319 hours were accumulated as pilot in command (PIC). The captain had been employed by Flying Tigers (since 15 May 1979) before becoming a FedEx pilot when the two companies merged in 1989. The captain holds an Airline Transport Pilot Certificate with an MD-11 Type Rating.[19] During a post-accident interview the captain reported that he had received FedEx's tailstrike awareness training several times over the years, including during first officer training.[20]

The captain arrived in Anchorage from his home the day before the accident flight and went to bed approximately 10:00 p.m. local time. He arose the day of the accident flight at approximately 8:30 a.m. and felt rested. He reported that he was in good health and has not had any significant life changes in the last 12 months. He is married with two children.[21]

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[15] Group Chairman's Factual Report Operations /Human Performance Group, Attachment 5A page 9.
[16] Structures Group Chairman's Factual Report of Investigation, page 2.
[17] Structures Group Chairman's Factual Report of Investigation, page 2.
[18] Structures Group Chairman's Factual Report of Investigation, page 2.
[19] Group Chairman's Factual Report Operations /Human Performance Group, pp. 6-7.
[20] Group Chairman's Factual Report Operations/Human Performance Group., Attachment 5C page 3.
[21] Group Chairman's Factual Report Operations /Human Performance Group, Attachment 5A pp. 12-15.

The first officer had accumulated about 3,111 hours, of which about 1,200 were accumulated as a flight engineer while employed at Delta Air Lines. His previous flight time had been accumulated in the Navy, and about 95 hours had been accumulated in the MD-11 at FedEx (all as first officer). The first officer holds an Airline Transport Pilot Certificate with Type Ratings for the L-188 and the MD-11.[22]

The first officer had two days off before the accident flight. The night before the flight he went to bed around midnight and woke at about 6:30 a.m., drove a friend to the airport, then returned to bed and slept until about noon before reporting for the trip at about 2:00 p.m. The first officer reported that he was healthy and no significant life changes had occurred in the last 12 months. He is married and has three children.[23]

1.6 AIRCRAFT INFORMATION

The accident aircraft was an MD-11-F (Freighter), Fuselage Number 553, Serial Number 48604, U. S. Registration Number N611FE. At the time of the accident the aircraft had accumulated approximately 13,034 hours and 2,950 landings.[24] BLBD records indicate that the accident aircraft had previously experienced a hard landing and a tail strike.

The accident aircraft had a maximum allowable taxi weight of 628,000 lb.; a maximum allowable start-of-takeoff weight of 625,500 lb.; a maximum allowable landing weight of 481,500 lb.; and a maximum allowable zero fuel weight of 451,300 lb.[25]

On the accident flight, the start-of-takeoff weight was calculated by FedEx to be 556,762 lb., with a center of gravity (CG) of 24.8% mean aerodynamic chord (MAC).[26] Landing weight and CG were later estimated by FedEx to be approximately 452,000 lb. and 23.6% MAC, respectively.

The MD-11 is a large, "wide body" transport aircraft, has a wing span of approximately 170 ft. (winglet tip to winglet tip), and is approximately 200 ft. long.

The MD-11 was certified to Title 14 Code of Federal Regulations Part 25, as amended by Amendments 25-1 through 25-61, and as defined in FAA Type Certification Data Sheet A22WE. The MD-11 received its Type Certificate on November 8, 1990.

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[22] Group Chairman's Factual Report Operations /Human Performance Group, pp. 7-8.
[23] Group Chairman's Factual Report Operations /Human Performance Group, Attachment 5A pp. 10-11.
[24] Group Chairman's Factual Report Operations /Human Performance Group, pp. 8-9.
[25] FedEx MD-11 Flight Crew Operating Manual, Volume II, LIM-10-01.
[26] Group Chairman's Factual Report Operations /Human Performance Group, pp. 9-10.

1.7 METEOROLOGICAL INFORMATION

The hourly surface observation METAR (Aviation Routine Weather Report) for Newark at 00:51 EST/04:51 UTC was: 8,000 ft. scattered cloud layer, 10 statute miles visibility, winds 240° magnetic at 10 knots (kt.), with temperature 20° centigrade (C), dewpoint 12° C, and altimeter setting 30.23 inches mercury (in. Hg.).[27] At 01:51 EST/05:51 UTC measured surface winds were 260° magnetic at 7 kt., temperature 67° F, altimeter 30.22 in. Hg.[28]

1.8 COMMUNICATIONS

There were no reported communications difficulties with air traffic control during the accident flight.

1.9 AIRPORT INFORMATION

Newark International Airport (KEWR) is located approximately 3 miles south of the City of Newark. Airport elevation is listed as 18 ft. above mean sea level (MSL). KEWR is owned by the City of Newark and operated by the Port Authority of New York and New Jersey. The airport is served by three runways; 04L/22R, 04R/22L, and 11/29.

Newark runway 22R, the accident runway, is 8,200 ft. long by 150 ft. wide, and has a displaced threshold of 440 ft. Useable runway after glideslope intercept is listed on Jeppesen charts as 6,860 ft. Runway 22R is equipped with a Category I Instrument Landing System (ILS) approach, a visual approach slope indicator (VASI), high-intensity runway edge lights (HIRL), runway end identifier lights (REIL), and runway centerline lights (CL). Runway 04L (same runway, opposite direction) has a displaced threshold of 740 ft. Useable runway after glideslope intercept is listed by Jeppesen as 6400 ft. Runway 04L is equipped with a Category I ILS approach, HIRL, CL, touchdown zone lights (TDZ), and a medium intensity approach lights system with runway alignment indicator lights (MALSR). The runway surface is asphalt and is grooved. Runway 04L/22R was resurfaced after the accident.

Runway 22L is 9,300 ft. long by 150 ft. wide, and has a displaced threshold of 1,090 ft. Useable runway after glideslope intercept is listed on Jeppesen charts as 7,395 ft. Runway 22L is equipped with a Category I ILS approach, HIRL, centerline and TDZ lights, lead-in lights, and MALSR. Runway 04R has a displaced threshold of 1190 ft. Runway 04R is equipped with a Category II ILS approach, HIRL, CL, approach light system with sequenced flashing lights (ALSF-II), and TDZ lights. The runway surface is asphalt and is grooved. At the time of the accident runway 04R/22L was closed.

[27] Group Chairman's Factual Report Operations /Human Performance Group, pp. 11-12.
[28] Airplane Performance Study, page 6.

Runway 11/29 is 6,800 ft. long by 150 ft. wide. Runway 29 has a displaced threshold of 298 ft. Runway 11/29 is equipped with HIRL, CL, REIL, and VASI. Runway 11 is also equipped with a Category I ILS approach.[29]

1.10 FLIGHT RECORDERS

The Fairchild Cockpit Voice Recorder (CVR) and the Sundstrand Data Control Universal Flight Data Recorder (UFDR or FDR) were recovered from the wreckage and sent to the NTSB laboratory for readout. Both recorders were operating and recording data at the time of the accident; both recorders exhibited evidence of momentary power transients during second touchdown impact.

In addition, several avionics units were removed from the aircraft for evaluation of the units' non-volatile memory (NVM). The results of the NVM evaluation are contained in section 1.14.1 of this report.

1.10.1 CVR Information

The CVR transcript began as Flight 14 was descending into the New York terminal area (see Appendix 5.1, Cockpit Voice Recorder Transcript). During the descent the flight crew discussed APLC stopping distances and appropriate autobrake settings.[30] The crew indicated that the flight deck went to a dark cockpit environment at CVR time 0104:58, approximately 28 min. prior to the accident. During the descent the left landing light was noted to be inoperative.[31] The crew reported the airport in sight and were cleared for the visual approach to 22R.[32] Tower reported the winds to Flight 14 as "two five zero at five".[33] The captain disconnected the autopilot after flaps were set to 50°, just prior to the first officer stating that the before landing checklist was complete. Automatic radio altitude callouts were recorded for 1000, 500, 100, 50, 40, 30, 20, and 10 feet[34]. Between the first and second touchdowns, and after second touchdown impact, the CVR recorded swearing by the flight crew.[35] There was a short-term loss in CVR audio (0.31 seconds) after second touchdown impact and an aural "tire failure" call repeated twice about 4.43 seconds after second touchdown impact.[36]

1.10.2 FDR Information

[29] Airport Group Chairman's Factual Report of Investigation.
[30] Cockpit Voice Recorder (CVR) transcript, pp. 2-4.
[31] CVR transcript, page 18.
[32] CVR transcript, page 30.
[33] CVR transcript, page 31.
[34] CVR transcript, pp. 34-35.
[35] CVR transcript, pp. 35-36.
[36] CVR transcript, page 36.

Tabular data and time-history plots were provided by the NTSB to the parties to the investigation in the Digital Flight Data Recorder Factual report. Selected time-history plots were developed from these data and are attached in Appendix 5.2.

It was noted from the supplied FDR data that the autopilot was OFF and autothrottles were ON during the later stages of the approach, and that the aircraft was tracking the localizer and glideslope to runway 22R. The aircraft was configured for a flaps 50° landing. The FDR recorded an approach speed of approximately 156 kt., which corresponds closely to a calculated V_{REF} + 5 speed of 157 kt. at 452,000 lb. Descent rate below 700 ft. was approximately 14 feet per second (fps) until just before first touchdown (the Jeppesen approach chart for runway 22R indicates that at a groundspeed of 160 knots, a descent rate of 861 feet per minute, or 14.3 fps, is required to maintain the 3.00° glideslope). Pitch attitude below 700 ft. varied just over ±1° from an approximately nominal value of 3°. FDR and radar data show the aircraft was stabilized on the approach.[37] At about 50 ft. radio altitude the throttles began to retard to flight idle, which is consistent with autothrottle logic. At 50 ft. radio altitude the aircraft was on localizer and on glideslope; the aircraft continued to precisely track the localizer and was either on or slightly above the glideslope until the first touchdown.[38] At about 35 ft. radio altitude, at approximately subframe 339.25, the aircraft's pitch attitude was approximately 2.5° ANU and decreasing slightly; a nose-up elevator deflection of about 7.5° at approximately subframe 339.75 transitioning to approximately 15° ANU by subframe 340.75 brought the pitch attitude to approximately 5° ANU. By subframe 341.25 the recorded elevator deflections were reduced to approximately 5° AND, and the recorded pitch attitude decreased to approximately 4° ANU by subframe 342.

In the 1 second time interval prior to the first touchdown (subframes 342-343) the recorded throttle resolver angles increased from approximately 40° to 70-75° (forward limit stop = 85.5°; takeoff setting = 78.3°; climb thrust = 68°; idle = 41°), or to 89-96% of the takeoff thrust setting angle, with corresponding recorded increased engine thrust parameters.[39] Concurrent with the throttle resolver angle increase, 20-25° nose-up elevator deflections were recorded (maximum available ANU elevator deflection is 35°), corresponding to 57-71% of maximum available elevator control surface travel. The aircraft touched down slightly right wing low (approximately 1° RWD) at approximately 7-8 fps and with a pitch attitude of

[37] Airplane Performance Study, page 1.

[38] See Appendix 5.2, G/S Dev. parameter. The Jeppesen airport charts 10-9 and 10-9A list the total length of Runway 22R as 8,200 feet. Distance remaining after the displaced threshold is listed as 7,760 ft. Distance remaining after glideslope intercept is listed as 6,860 ft.; therefore glideslope intercept is 900 ft. beyond the Runway 22 displaced threshold. Per the Airplane Performance Study, first touchdown was measured to begin 1,126 ft. beyond the Runway 22 displaced threshold .

[39] This increase in throttle resolver angle is beyond the 8° per second maximum rate at which the autothrottles can advance or retard throttles.

approximately 7° ANU (subframe 343), then became airborne for a period of approximately 3 seconds, reaching a recorded radio altitude height of about 5 feet. Maximum vertical acceleration recorded during the first touchdown was 1.67 g. At the beginning of the first touchdown the recorded vertical acceleration was 1.04 g, for an approximate Δg (maximum g – minimum g) of 0.63 g. The throttles were advanced sufficiently to prevent the spoilers from automatically deploying after the first touchdown (requires approximately 44°-49° or greater throttle resolver angle on the No. 2 engine throttle to disarm autospoilers and autobrakes).

While airborne between the first and second touchdowns, the aircraft initially continued to pitch further ANU until a maximum pitch attitude of 8.44° was recorded between subframes 343 and 344. Prior to reaching the maximum ANU pitch attitude, the FDR began to record a reversal in the elevator displacements towards the AND direction, reaching a maximum at subframe 344.5 of approximately 18° AND (maximum available AND deflection is 25°), or 72% of maximum travel, with a corresponding pitch rate of approximately 7 deg./sec. AND. Recorded throttle resolver angle decreased to approximately 50-55° prior to second touchdown impact with a corresponding recorded engine parameter decrease. The FDR recorded RWD aileron displacements and a corresponding aircraft RWD roll attitude between touchdowns (subframes 343-346). At second touchdown impact (subframe 346), maximum recorded roll attitude was 9.49° RWD,[40] recorded pitch attitude was 0.70° AND (for nearly a full second), and maximum recorded vertical acceleration was 1.7 g. RWD roll rate at the beginning of second touchdown impact was approximately 7° per second.[41] At the beginning of second touchdown impact the recorded vertical acceleration was 0.51 g, for an approximate Δg (maximum g – minimum g) of 1.19 g.

Between the start of second touchdown impact and the data drop-out (subframes 346-347.6), recorded roll angle decreased to about 4.5° RWD and the RWD aileron input appeared to be decreasing towards 0°; after the drop-out (subframe 349) the recorded roll attitude was 32.34° RWD, and the aircraft continued rolling further to the right until the end of the accident data. Recorded left wing aileron displacements were LWD after the drop-out; recorded right wing aileron displacements were nearly neutral; left wing spoiler displacements were approximately full deflection while the right wing spoilers were not deflected. At the end of the recorded accident data (subframe 352) the roll attitude was 86.48° RWD, the airspeed was 138.5 KIAS, and the groundspeed was 132 kts.

[40] A review of the recorded data taken during maximum demonstrated crosswind certification landings indicated that the roll attitude at touchdown for the flaps 35° landing was 0°; for the flaps 50° landing the roll attitude was 1°. However, maximum roll attitudes on approach were 6° and 7°, respectively, both of which were less than the roll attitude of 8-10° recorded by the accident aircraft at the second touchdown.
[41] Airplane Performance Study, page 3.

After the drop-out, recorded throttle resolver angles showed an increase to about 81° for all three throttles until the end of the accident data.

A sink rate analysis was performed by Boeing Long Beach Division (BLBD) and previously forwarded to the NTSB and parties to the investigation (Letter No. C1-L70-SRL-98-L098, dated 2 March 1998). Two plots from the analysis are included in Appendix 5.2. The analysis conservatively showed that the second touchdown impact descent rate at the RMLG was at least 13 fps (11 fps at the aircraft center of gravity plus approximately 2 fps at the RMLG due to RWD roll rate). The NTSB concluded that the RMLG sink rate at touchdown was approximately 13.5 fps.[42]

1.11 WRECKAGE AND IMPACT INFORMATION

The accident aircraft's first touchdown tire marks were noted to be approximately 1,126 feet beyond the displaced threshold of Runway 22R.[43] Tire marks associated with the accident aircraft's second touchdown impact on the RMLG began at approximately 1,924 ft. Runway scars associated with No. 3 engine nacelle ground contact began at approximately 2,164 ft. and continued until leaving the right side of the runway at approximately 3,476 ft. The first aircraft components in the wreckage path were pieces of composite material from the aircraft's right inboard flap, found at approximately 2,226 ft. The right wing inboard trailing edge flap was found on high-speed taxiway H at approximately 2,376 ft. The start of fuel burn marks, inboard of the No. 3 engine nacelle marks, began at approximately 2,506 ft. and continued until the aircraft left the runway at about 3,476 ft. Marks associated with the accident aircraft's tail contacting the runway began at approximately 2,644 ft.[44] It should be noted that while there were gouges documented in the runway surface starting at about 2,676 ft., there were no marks on the runway surface either before or after this point that were positively associated with right wingtip or right wing flap hinge structure ground contact.

All three engines separated from the aircraft and came to rest off the right side of the runway in the vicinity of the right wing. The separated right wing came to rest at approximately 4,577 ft. The RMLG strut, which had also separated from the right wing structure, came to rest at approximately 4,805 ft. The fuselage, which had remained intact, came to rest at approximately 5,126 ft.[45]

1.11.1 Fuselage

The fuselage came to rest upside down, rolled towards and leaning on its left wing approximately 580 ft. to the right of the runway centerline. Fire fighting and

[42] Airplane Performance Study, pp. 3, 7.
[43] All distances are in feet, measured from the Runway 22R displaced threshold.
[44] Airplane Performance Study, pp. 4-5.
[45] Structures Group Chairman's Factual Report of Investigation, pp. 2-4.

hazardous materials crews were on scene and in the aircraft prior to the beginning of documentation; fire damaged or destroyed much of the inboard right wing structure, and fire/hazardous materials amelioration efforts may have contributed to the right inboard wing structure damage.

The top of the cockpit section was wrinkled and pinched between the ground and the cockpit windows. The captain's sliding side window was open and all six windows were damaged, apparently by fire axes. The right side of the cockpit exterior was lightly sooted. The cockpit/forward fuselage right side skin was wrinkled and scraped through to metal, from the upper aft corner of the aft right cockpit window to the forward edge of the R2 door. The nose landing gear was intact with tires inflated. The R1 door was open approximately 2 ft. The entire fuselage suffered extensive fire damage along the right side. The upper fuselage was structurally damaged from coming to rest upside down.

The main cabin floor was burned through the entire length (from just aft of the cockpit to the aft pressure bulkhead). Portions of the right and underside fuselage skin had burned or melted away. The fuselage skin had been cut away at station (Sta.) 1761 from the ground up to mid window level, then aft to a burned out area extending from the forward edge of the R4 door to the aft pressure bulkhead.

The entire left side of the fuselage, and the left wing, were heavily sooted. Two engine fan blades were embedded in the fuselage forward of and above the left wing leading edge.

The left and right landing lights were found in the extended position.[46]

1.11.2 Tail Section

The vertical stabilizer, the No. 2 engine, and the outboard half of the right horizontal stabilizer's outboard elevator separated from the fuselage. The outboard end of the left horizontal stabilizer was fractured.[47]

1.11.3 Left Wing

The left wing and LMLG remained attached to the fuselage, and all of the left wing control surfaces except for the No. 8 slat remained attached to the wing. The spoilers were found in the extended position. The No. 1 engine and pylon had separated from the wing. The aft pylon bulkhead had failed through its mounting lugs and the forward pylon bulkhead was completely sheared out of the pylon's box structure.

[46] Structures Group Chairman's Factual Report of Investigation, pp. 4-6.
[47] Structures Group Chairman's Factual Report of Investigation, page 7.

1.11.4 Right Wing

The right wing separated from the fuselage just inboard of the wing MLG and fuel closure bulkhead at wing station 264. The outboard upper surface was intact and sooted. Buckling was noted in the upper surface skin approximately 12 feet inboard from the tip. The lower wingtip "winglet" had separated from the wingtip at its attach surface. The upper "winglet" remained attached to the wingtip. The No. 3 engine and pylon had separated from the wing completely and the engine remained attached at the aft and forward pylon mounts.

All leading edge control surfaces outboard of wing station 264 remained attached to the wing. The inboard flap structure had separated from the wing (the full 20-ft. section of right inboard flap was found on taxiway H); portions of the separated flap hinge bracket structure were found close to the wing trailing edge.

Descriptions of the RMLG support fitting, bracing structure, right wing inboard structure, and the results of laboratory examinations of these components are contained in MDC 98K1023 and MDC-98K1023/1, which were attached to the Systems Group Chairman's Factual Report of Investigation.

Stringers at the inboard end of the right wing upper surface, as well as the upper surface chord-wise fracture surface, were documented as having been bent in an upward direction. The rear spar fracture near wing station 264 was documented as having been bent aft.[48]

The Structures Group reconvened in Newark on 21 April 1998 to re-examine the right wing and inboard right wing spars. Examination of the wing lower surface revealed that it was buckled and fractured approximately 9 feet inboard from the wing tip. The fracture surface was clean, indicating that the fracture most likely occurred after the accident during wreckage recovery operations. Span-wise scrape marks were noted on the outboard wing undersurface. The upper surface of the wing skin, 12 feet from the wing tip, was buckled upwards and the adjacent inboard skin exhibited compression wrinkling. Portions of the aft rear spar and caps were removed and forwarded to BLBD for laboratory examination. A portion of the right rear spar web, identified in photographs and targeted for retrieval and laboratory examination, had been disposed of following the earlier release of the wreckage.[49]

1.11.5 Main Landing Gear

All three main landing gears were recovered from the wreckage and forwarded to BLBD for laboratory examination and documentation. The results are noted in MDC 98K1023.

[48] Structures Group Chairman's Factual Report of Investigation, pp. 8-9,
[49] Addendum to Structures Group Factual Report of Investigation, pp. 2-5.

1.11.6 Engines

Described in the NTSB's Systems Group Chairman's Factual Report of Investigation.

1.11.7 Metallurgical Examination

The right main landing gear (RMLG), left main landing gear (LMLG), center landing gear (CLG) and related assemblies and components; right inboard flap, and portions of the right inboard wing structure were forwarded to Boeing Long Beach Division facilities in Long Beach, California, for examination and analysis, under NTSB supervision and with party participation. Examination of the landing gear, wing, and flap components indicated that the primary fractures of all failed parts occurred by ductile overload failure; all parts, components, and assemblies met drawing specifications (with one minor exception); and that all intergranular secondary cracks were the result of stress corrosion cracking and occurred after the accident sequence. See reports MDC 98K1023 and MDC-98K1023/1. Illustrations 1 and 2 detail RMLG components and the trapezoidal (trap) panel.

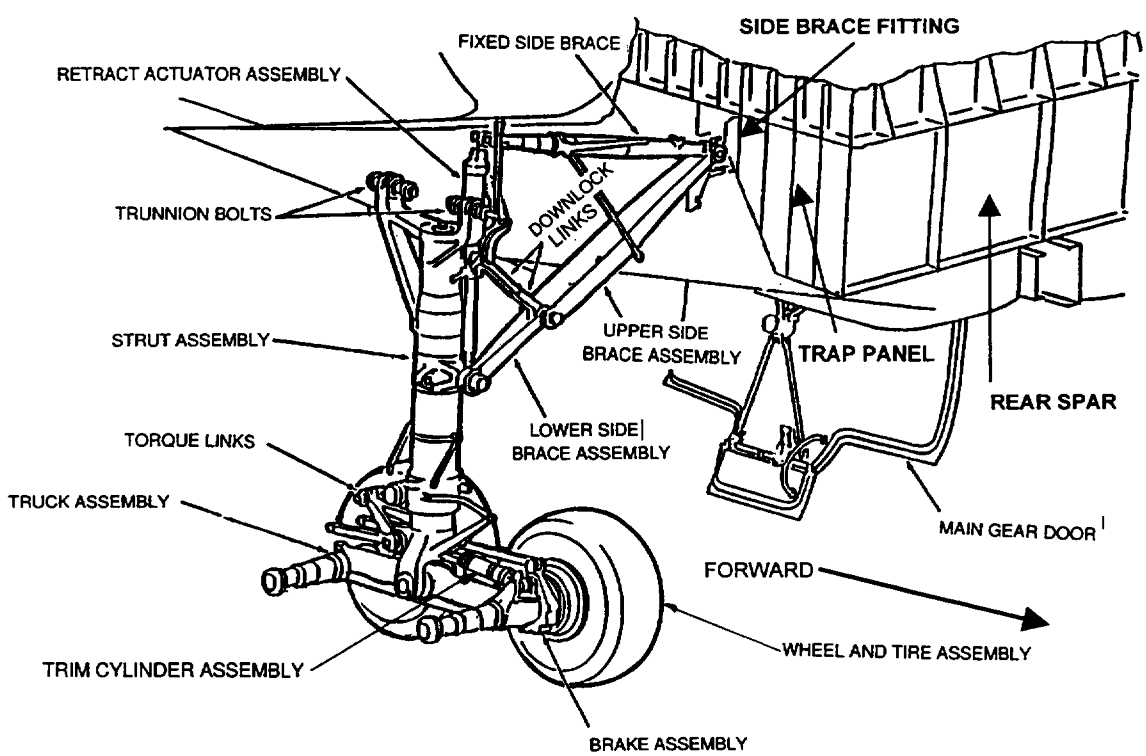

Illustration 1
RMLG Components

1.11.7.1 Trapezoidal Panel

The RMLG side brace fitting (sometimes called the "pillow block") was found still connected to the fixed side brace and the upper folding side brace. Also, a portion of the trapezoidal panel was found connected to the side brace fitting by the intact inboard side-brace-fitting-to-trap-panel attach bolt. The trap-panel-piece fracture surfaces were obliterated by abrasion due to runway contact. Examination of the bolt revealed it was bent slightly in the outboard and aft directions (see Figure 45 of MDC 98K1023). The bend in the bolt is consistent with loads having been applied to it by the side brace fitting in two directions, (1) a bending moment about the aircraft (nose down) pitch axis, and (2) a bending moment about the aircraft roll (right wing up) axis (see page 20 of MDC 98K1023).

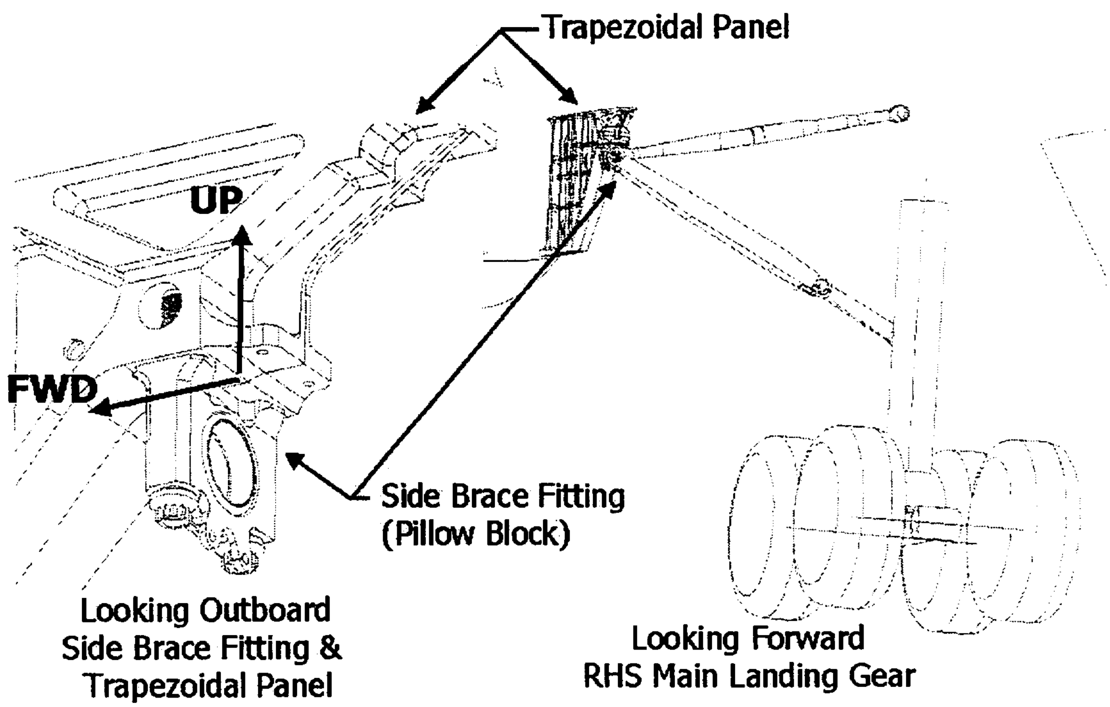

Illustration 2
Side Brace Fitting and Trapezoidal Panel

The outboard side-brace-fitting-to-trap-panel attach bolt was fractured transversely through the shank portion of the bolt at the interface between the side brace fitting and the trap panel. The threaded portion of the bolt was found in the trap panel; the remainder of the bolt was found on the runway (see Figures 46-48 of MDC 98K1023). Examination showed that the outboard bolt failed primarily due to a shear overload with the origin of the failure on the outboard side of the bolt. The fracture face was smeared indicating that the bolt was subjected to a compression load as it sheared. The fracture face was also dramatically sloped indicating a bending load was present. See Figures 164 and 165 of MDC 98K1023. (The presence of a bending load is also indicated by the bolt showing evidence of being loaded in compression since binding of the bolt inside the side brace fitting is necessary for the side brace fitting to apply such a load). The exposed end of the piece of the bolt still attached to the trap panel was mechanically damaged by contact with the side brace fitting. (The tip of the fracture was broken off as the side brace fitting moved inboard and the tip was "hooked" on the outboard edge of the outboard attachment hole in the side brace fitting). Altogether, this damage is consistent with the side brace fitting having applied to the bolt (1) an inboard-acting shear load, (2) a bending moment about the aircraft (right wing up) roll axis, and (3) an axial compression load.

The side brace fitting exhibited mechanical damage along the lower surface of its two outboard flanges, which coincide with mechanical damage observed along the inner edges of the fixed side brace inboard end clevis lugs (see page 28 and Figures 50, 51, and 84 from MDC 98K1023). This damage is consistent with contact of the fixed side brace clevis against the side brace fitting and its applying to the side brace fitting a moment about the aircraft (right wing up) roll axis via "prying action". The mechanical damage on the aft flange was more pronounced than that on the forward flange. The aft flange was bent up approximately 0.02 inches.

Impressions from the aft flanges of the side brace fitting were left on both the inboard and outboard halves of the trap panel, aft of the side brace fitting attachment holes. This damage is consistent with the side brace fitting "rocking" about the aircraft (nose down) pitch axis. The impression was deepest at the outboard aft corner (see Figure 52 from MDC 98K1023).

As discussed above, abrasion due to runway contact obliterated the fracture surfaces on the inboard trap-panel-piece found attached to the side brace fitting. However the mating surfaces on the inboard half of the trap panel were intact and were examined. The fracture origins of 3 cracks are shown in Illustration 3 below (the origins are represented as stars, and are numbered such that star 1 corresponds to crack 1, etc.). These fractures are consistent with a failure caused predominantly by a tension load applied by the inboard side-brace-fitting-to-trap-panel attach bolt. Such a tension load is further consistent with the fixed side brace clevis lugs contacting the side brace fitting (as discussed above) and the associated presence of a large "prying" moment about the aircraft (right wing up) roll axis.

To summarize, the evidence from the right-hand trap panel, side brace fitting, and fixed side brace inboard clevis, together, indicate that the overload failures were consistent with application of the following loads:

1. a load pushing the side brace fitting up against the bottom of the trap panel.
2. a load moving the side brace fitting inboard relative to the trap panel.
3. a moment "rocking" the side brace fitting about the aircraft pitch (nose down) axis.
4. a "prying" moment about the aircraft roll (right wing up) axis, applied to the side brace fitting by the fixed side brace.

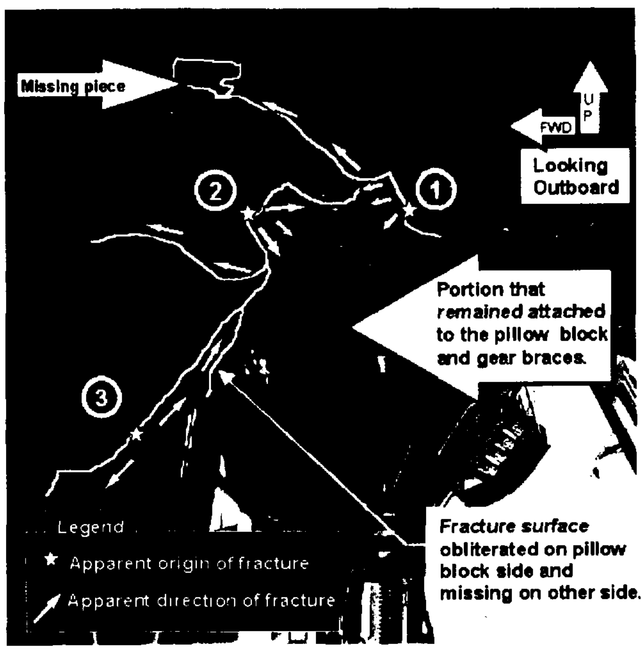

Illustration 3
Inboard Right Trapezoidal Panel

1.11.7.2 RMLG Assembly

Illustrations 1 and 2 show the component locations of the right main landing gear (RMLG). The fixed side brace, as described in MDC 98K1023 on pages 27 and 28, was found with a transverse fracture separation approximately 12 inches from the outboard end. The fixed side brace was bent in the aft direction relative to the RMLG-to-wing fitting.

The outboard segment of the fixed side brace was found attached to the RMLG-to-wing attach fitting. The inboard end of the fixed side brace was found attached to the side brace fitting and inboard trap panel segment.

The upper and lower folding side braces, described in MDC 98K1023 on page 27, were found to be twisted approximately 0.5° and 16.0°, respectively. The direction of the twist is clockwise, looking inboard while held at the inboard end.

Examination of the trim actuator assembly (MDC 98K1023, page 19) indicated that it had "bottomed out" in both the extension and retraction directions. The piston rod evidenced damage consistent with severe compressive loading. Further, the piston rod had fractured transversely and the eye bolt end of the rod was still attached to the piston; the aft end of the trim actuator was still attached to the truck beam. The bottom portion of the eyebolt assembly was mechanically damaged in an area that aligned with a dent in the primary failure origin area on the truck beam.

The outboard faces of the oleo strut cylinder trunnion arms exhibited impact damage areas that were consistent with the damage on the RMLG-to-Wing attach fitting clevis areas (figures 7 through 11, MDC 98K1023).

The forward trunnion bolt was found fractured and separated at its forward "zero margin" groove (MDC 98K1023, pages 31-34 and Figures 104-108). The forward portion of the bolt was found on the runway.

Dimensional inspection of the axles indicated that the forward axle was bent 0.027 inches at the inboard end and 0.017 inches at the outboard end (MDC 98K1023, page 24).

1.11.7.3 RMLG Attach Fitting

Examination of the wing attachment support fitting (attach fitting), described in MDC 98K1023 on pages 14 and 15, revealed that the lower portions of the inner surfaces of both the lower forward and aft clevis areas evidenced impact damage coincident with impact damage found on the outboard surface of the RMLG shock strut cylinder trunnion arms (Figures 7-11, MDC 98K1023). Alignment of these marks are consistent with the RMLG swinging outboard, with the trunnion bolts and attach fitting still intact, with sufficiently high forces to inflict the above described impact damage to both components.

Post-accident examination of the RMLG-to-wing attach fitting revealed that the aft lug of the lower forward clevis and both lugs of the aft clevis were separated from the attach fitting. The fixed-side-brace-to-wing attach clevis lugs had not failed and still retained the outboard end of the fixed side brace. Both trunnion bolts from the RMLG were recovered, but since the aft trunnion bolt had not failed, only the forward bolt was examined in the laboratory. The forward bolt, documented in MDC 98K1023, pages 31-33, was failed at its "zero margin" groove. The bolt evidenced characteristics consistent with overload failure in a downward and outboard direction.

1.11.7.4 Right Inboard Flap Segment

Examination of the inboard flap track, described in MDC 98K1023, pages 43-45, revealed failures consistent with an outboard motion of the flap segment relative to the fuselage. Fracture 3, which consisted of a missing portion of the upper track flange, aligned with the two fuselage-mounted side rollers when the flap was in the extended position.

1.11.7.5 Right Wing

The examination of right wing inboard structural components is described in MDC-98K1023/1. Two major sections were examined: (1) the intersection of the bulkhead at station X_{ORS} 264 with the RMLG-to-wing attach fitting and the outer wing rear spar assembly (pages 8-11, MDC-98K1023/1); and (2) the intersection of the right trapezoidal panel with the center wing bulkhead and outer wing rear spar (pages 11-16, MDC-98K1023/1). All fractures were consistent with ductile overload failures with no materials or dimensional discrepancies noted.

The upper and lower spar caps from section 1 above, near the main landing gear attach fitting, evidenced bending and fracturing in the aft direction. The MD-11 rear spar has a forward and an aft web. The aft rear spar inner web was bent in the aft direction. The forward rear spar web, aft rear spar inner web, and upper stringer #1 exhibited fractures and buckling consistent with an upward, shearing load applied to the rear spar assembly.

The components from section 2 above, near the wing root area, were examined and evidenced aft (outer wing upper rear spar cap vertical leg, rear spar and rear spar inner webs near the upper and lower spar caps) and upward (outer wing upper aft surface skin, base flange of rear spar cap, outer wing lower stringer) bending.

The above-described damage in the vertical plane is consistent with an overload failure in the rear spar web inboard of the main landing gear. The aft-bending damage described above is consistent with the outboard wing moving aft relative to the inboard wing stub.

1.12 FIRE

The accident aircraft caught fire during the accident sequence while the aircraft was in motion on the runway and continued to burn after coming to rest. Jet fuel from the separated right wing, and later, the aircraft's cargo (once the fuselage was breached from the outside), were the fuel for the sustained fire.[50] Airport fire fighters were on scene immediately after hearing the tower-triggered alarm, and fought the fire continuously for the next approximately 5 ½ hours. The fire fighters assumed that there were hazardous materials (Haz Mat) in the aircraft's cargo and asked for a manifest from the operator. Within approximately 25 minutes a hand-written manifest was provided; the information in the manifest indicated that the smoke from the fire may be toxic and that some of the chemicals may react violently with water. Twelve fire fighters suffered smoke-inhalation difficulties and one was taken to a nearby hospital for treatment.[51]

The first officer reported that after the aircraft came to rest he was able to go back to the courier area to assist the passengers with their exit from the aircraft. While assisting the passengers from their seats and attempting to open the R1 door, he noticed smoke entering the courier area from the cabin either through the zipper area of the smoke barrier or from a tear in the barrier itself (he apparently wasn't certain). He then tried to open the L1 door but couldn't pull the handle due to interference from debris. By this time the captain had opened his side window and all on board escaped via the window. Actual elapsed time from the time the aircraft came to a stop to the last person exiting the aircraft is not known. However, the first officer was the last to leave the aircraft and he recalled seeing fire trucks coming towards them and a fire engine parked just in front of the nose of the aircraft as he exited.[52] The captain reported that fire engines arrived at the aircraft within 2 minutes of the accident.[53]

1.13 SURVIVAL ASPECTS

The first officer reported that he had attempted to open the forward right passenger entrance door but the door would not open more than about an inch, and when he went to the forward left door it was blocked by debris. By that time the captain had opened his side window and the evacuation took place .

The passenger entrance doors on the MD-11 are plug-type doors and open inward (into the cabin) then upward into the fuselage overhead. All passenger entrance doors on MD-11-F aircraft are deactivated except for the forward left (L1) and right (R1) doors. Documentation of the R1 door after the accident indicated that it was open approximately 2 feet.[54] The partially (vs. fully) opened

[50] Structures Group Chairman's Factual Report of Investigation, pp. 1-10 and Appendices; Airplane Performance Study, page 5.
[51] Hazardous Materials Group Factual Report, pp. 5-7.
[52] Group Chairman's Factual Report Operations /Human Performance Group, Attachment 5A page 9.
[53] Group Chairman's Factual Report Operations /Human Performance Group, Attachment 5A page 14.
[54] Structures Group Chairman's Factual Report of Investigation, page 5.

forward door may have been the result of structural damage to the fuselage overhead when the aircraft rolled inverted. However, due to the lengthy firefighting and Haz Mat efforts, the condition and potential operability of the (active or inactive) doors, other than the R1 door, immediately after the aircraft came to rest, is not known.

1.14 TESTS AND RESEARCH

1.14.1 Non-Volatile Memory (NVM)

The components listed below were recovered from the accident aircraft and returned to their respective manufacturers for non-volatile memory (NVM) data recovery. It should be noted that the data stored in NVM is time-tagged to the nearest minute rather than the nearest second.

Description	Quantity	Manufacturer	P/N
DEU	3	Honeywell	4059011-909
MCDU	3	Honeywell	4059051-902
IRU	3	Honeywell	HG1150BD02
FCC	2	Honeywell	4059001-907
FMC	2	Honeywell	4059050-911
DADC	3	Honeywell	4059060-901
Hyd Sys Contr.	1	Honeywell	4059021-903
Misc Sys Contr.	1	Honeywell	4059027-903
FADEC	1	GE	1519M91P06
FADEC	1	GE	1519M91P07
FADEC	1	GE	1820M34P02

1.14.1.1 Display Electronics Units (DEUs)

The Part Number 4059011-909 units, Serial Numbers 96060708, 920405548, and 90060190 were examined and downloaded by Honeywell. The downloaded data were forwarded to Boeing for review. The type of data stored in the DEUs are fault codes, error messages, time (UTC), airspeed, and altitude, which are recorded at the time of each fault. The fault codes were examined to see if there had been a trend of specific error messages during the accident flight and previous flights, with no such trend found. There were unrelated faults logged on flights prior to the accident flight. No faults were logged on the accident flight, or at the approximate time of the accident.

1.14.1.2 Multifunction Control Display Units (MCDUs)

The Part Number 4059051-902 units, Serial Numbers 91060373, XXXX0678, and 93050680 were examined and downloaded by Honeywell. The downloaded data were forwarded to Boeing for review. The type of data stored in the MCDUs are fault codes and error messages recorded at the time of each fault. Performance data such as airspeed, altitude, attitude, etc., are not recorded. The fault codes were examined to see if there had been a trend of specific error messages during the accident flight and previous flights, with no such trend found. There were unrelated faults logged prior to the accident flight. No faults were logged on the accident flight.

1.14.1.3 Inertial Reference Units (IRUs)

The Part Number HG1150BD02 Inertial Reference Units' A4 Circuit Card Assemblies (CCAs) Serial Numbers 7651 (from IRU #2) and 7029 (from IRU #3) were examined and the NVM downloaded by Honeywell. IRU #1 was damaged by fire to the extent that NVM recovery was not possible. Since the IRUs were not powered-down normally, the accident flight fault items normally written to the A1 circuit cards were not entered into the cards' NVM. Therefore, recovery of the A1 cards' NVM was not attempted. Data from the A4 cards, which did record some low-level faults during the accident flight (used primarily by maintenance to assist with trouble-shooting), were forwarded to Boeing for review.

Data from the A4 circuit cards for both IRUs #2 and #3 showed ADC1 and ADC2 faults at 05:32 UTC on 7/31. Both cards also listed several sensor faults that may be consistent with the accident sequence, however, date and time were not recorded for these faults. Both IRU's logged multiple B0, B1, and B6 faults on previous flights. B0 faults are "No Data/Data Freshness-FMC-1" and B1 faults are "No Data/Data Freshness-FMC-2." B6 faults are "CFDS Automatic Command Freshness and Validity" faults (CFDS = Central Fault Display System).

1.14.1.4 Flight Control Computers (FCCs)

The Part Number 4059001-907 units, Serial Numbers 0326 and 0549 were examined and downloaded by Honeywell. The downloaded data were forwarded to Boeing for review. The type of data stored in the FCCs are fault codes and error messages, reporting CPU, failed monitor, suspected LRU source, airspeed, and altitude, all recorded at the time of each fault. These faults generally fall into two categories: surface feedback transducer monitor failures, and Inertial Reference Unit (IRU) and Air Data Computer (ADC) sensor parameter failures. The fault codes were examined to see if there had been a trend of specific error messages during the accident flight and previous flights, with no such trend found. There were unrelated faults logged prior to the accident flight and again on the accident flight; multiple faults, explained below, were logged at approximately the time of the accident. See Appendix 5.3.

The surface feedback transducer monitor failures (e.g. AIL MOD LVDT, EL RAM LVDT, etc.) are indicative of the FCC recognizing a no-voltage situation for these electrical inputs. Since all three control surfaces (aileron, elevator, and rudder) failed at the same time, this would tend to correspond to wire/cable and/or excitation power failures resulting from the breakup of the aircraft after runway contact.

Inertial Reference Unit (IRU) and Air Data Computer (ADC) sensor parameter failures consist of the following fault messages: Y RATE INV, VERT ACC INV, CAS INV, etc. The FCCs continuously monitor the IRU digital outputs, as well as comparing the like parameters across all three IRUs. The same is true for the dual ADC inputs. The fact that all of these parameters from both of these sensor systems failed at the same time supports the conclusion that these failures are the result of either loss of power/inputs to these sensors (in the case of the ADC), or the IRUs invalidating these outputs as a result of the unusual rates and attitudes encountered as the aircraft rolled over.

The "CFDS CMDS INV" fault message which occurred at 1200 ft. MSL at 0530 GMT is a known "nuisance fault" which corresponds to a lack of communication between the FCC and the Central Fault Display Interface Unit (CFDIU).

If the accident aircraft was in the Dual Land mode when the autopilot was disengaged, then the aircraft's electrical power buses were isolated before and after autopilot disconnect. Additionally, none of the stored FCC faults indicate that Dual Land would not have been available. If the assumption is made that the line replaceable units (LRUs) powered by the Number 3 system lost power before the LRUs powered by the Numbers 1 and 2 systems, then it appears that, by comparing recorded airspeeds, S/N 0549 was FCC-1 and S/N 0326 was FCC-2.

1.14.1.4.1 Longitudinal Stability Augmentation System (LSAS)

LSAS (Longitudinal Stability Augmentation System) inputs to and outputs from the FCC are continuously monitored, even when the LSAS is not actively commanding the elevators (e.g. below 100' AGL). When these monitors detect a failure, a fault is stored in FCC maintenance memory. Any failures detected with respect to LSAS inputs/outputs will also result in the affected LSAS channel(s) being shut down. The shut down is accomplished by de-energizing the elevator's electrical shut off valves that, when energized, permit LSAS commands to move the elevator. Further, the shut down would be annunciated to the flight crew via the LSAS FAIL lights on the overhead panel, as well as EIS (Electronic Instrument System) alerts (providing there are no display system inhibits in effect); an LSAS "Fail" would also be logged in the UFDR if the fault was sustained sufficiently long to be recorded by the UFDR (each LSAS channel is sampled twice per second). There were no LSAS failures recorded by the UFDR during the accident landing.

The FCC-logged "LSAS Failure" fault messages listed in the above tables occur at speeds below the first and second recorded touchdown speeds (149 kts. and

152.5 kts., respectively).[55] Therefore, those faults occurred at some point after second touchdown impact.

The "Dual Land Availability Failures" (fault No. 3 for S/N 0549 at 152 kts.; fault No. 2 for S/N 0326 at 148 kts.) resulted from Pitch Attitude Rate Invalid monitor input. This input is monitored continuously by LSAS and used by LSAS when active (since the autopilot has a higher priority than LSAS, the fault was logged against an autopilot function and not LSAS). Had LSAS been active when either of these faults were sensed, LSAS would have been shut down as described in the previous paragraph. It should be noted that the logged FCC faults were consistent with FCC faults observed after previous MD-11 hard landings, and which BLBD believes to be, at least in part, the result of an impact loading trauma to the main avionics rack.

1.14.1.5 Advanced Flight Management Computers (AFMCs)

The Part Number 4059050-911 units, Serial Numbers 00004581, and 00006328 were examined by Honeywell. AFMC S/N 00006328 lost its data due to battery failure. The downloaded data from AFMC S/N 00004581 were forwarded to Boeing for review. The type of data stored in the AFMCs are fault codes, airspeed, altitude, time, and error messages recorded at the time of each fault. The fault codes were examined to see if there had been a trend of specific error messages during the accident flight and previous flights, with no such trend found. There were unrelated faults logged prior to the accident flight and only one fault logged on the accident flight, after second touchdown impact (at 0532 UTC and 145 kts.), indicating an improper power-down of the AFMC.

1.14.1.6 Digital Air Data Computers (DADCs)

The Part Number 4059060-901 units, Serial Numbers 0229, 0309, and 0565 were examined and downloaded by Honeywell. The downloaded data were forwarded to Boeing for review. The type of data stored in the DADCs are BIT (Built-In Test) Test failures that occur in flight.[56] Neither performance data nor date and time are recorded with the faults. A maximum of 6 faults can be stored per flight, and there are 33 separate BIT Tests performed by the DADC monitoring system.

S/N 0229 DADC recorded 6 faults on the accident flight: "BIT Test 2 = No. 2 (right) AOA Input Failure"; "BIT Test 1 = No. 1 (left) AOA Input Failure"; "BIT Test 7 = Baro-Correction (Bus B Failure) Input Failure"; "BIT Test 6 = Baro-Correction (Bus A Failure) Input Failure"; "BIT Test 3 = Tip Tank Fuel Qty (Bus A Failure)

[55] The airspeeds logged with these faults are generated by the DADC and are routed to the CFDS via the FMCs, resulting in a latency of less than 0.5 seconds from generation to storage.
[56] A flight is defined as from the time the airspeed exceeds 100 knots (after having gone below 90 knots) to the time the airspeed goes below 100 knots. A loss of power is also treated as the end of a flight.

Input Invalid"; and "BIT Test 29 = Indicated AOA Fail". No faults were logged from previous flights. BIT Test failures 3, 6, and 7 are consistent with loss of power to or failure of the input sensors to the ADC. BIT Test 29 failure uses the results of BIT Tests 1, 2, and 27 to determine if indicated angle of attack (AOA) is valid. In basic terms, BIT Tests 1 and 2 check for a valid AOA input to the ADC, while BIT Test 27 compares the 2 AOA inputs to a specified tolerance.

S/N 0309 DADC recorded 1 fault on the accident flight: "BIT Test 29 = Indicated AOA Fail". On the previous 5 flights there were multiple logs for "BIT Test 29 = Indicated AOA Fail" and "BIT Test 27 = Angle of Attack Comparison" faults.

S/N 0565 recorded no faults.

Based on the same logic that was used above to identify FCC position, it appears that DADC S/N 0229 was DADC-1, S/N 0309 was DADC-2, and S/N 0565 was DADC-AUX.

1.14.1.7 Hydraulic Systems Controller (HSC) and Miscellaneous Systems Controller (MSC)

The Part Number 4059021-903, Serial Number 91030242 Hydraulic Systems Controller and the Part Number 4059027-903, Serial Number 91090276 Miscellaneous Systems Controller were examined and downloaded by Honeywell. The downloaded data were forwarded to Boeing for review. The type of data stored in these units is the day, month, GMT, flight number, fault code and error messages recorded at the time of each fault. No performance data are recorded.

The fault codes were examined to see if there had been a trend of specific error messages during the accident flight and previous flights. For the month of July 1997, the HSC NVM recorded no faults For the month of July 1997, the MSC NVM recorded three left static heater, two DEU-2, two CFDIU, one DEU-3, and one MSC faults. There were no faults logged on the accident flight prior to the time of the accident on either the HSC or the MSC. At 0532 the HSC logged a SYS 3 PRESSURE SENSOR fault, which is a result of a loss of feedback from the pressure sensor. At the same time, the MSC logged an ENGINE 3 IGNITION A LOGIC fault, which is a result of the MSC not receiving feedback from the No. 3 engine igniters, and other faults associated with the loss of various data busses.

1.14.1.8 Full Authority Digital Engine Controllers (FADECs)

Three electronic control units (ECUs) were recovered from the engine FADEC systems. The FADEC systems also include sensors, actuators, and the hydromechanical unit (HMU) in addition to the ECUs. The Part Number 1519M91P07, Serial Number ECDD6627; Part Number 1519M91P06, Serial

Number ECDD6071; and Part Number 1820M34P02, Serial Number ECDD6834 ECUs were examined and their respective non-volatile memories downloaded by Lockheed Martin Control Systems for GE. The downloaded data were forwarded to Boeing for review. The type of data stored in the ECUs are fault codes; error messages; snapshot performance data taken at the time of the fault, such as altitude, total air temperature, total pressure; and data such as flight legs, engine maximum power time, electronic control unit (ECU) over-temperature time, maximum temperature, engine cycle counter, part number and serial number of the ECU, and various solenoids and valve positions. The fault codes are classified as *No Dispatch Faults* and *Dispatchable Faults* (Short Time Dispatch Faults, Long Time Dispatch Faults, and Other Maintenance Items or Aircraft EAD/MMEL Faults).[57] Dispatchable Faults have no direct impact on loss of thrust control.

The NVM-recorded fault codes were examined to see if there had been a trend of specific error messages during the accident flight and previous flights.

S/N ECDD6627 (Engine No. 3) ECU, on both channels, recorded a trend of "ESCV Solenoid Wrap Fault" messages (Dispatchable Fault-Other Maintenance Items or Aircraft EAD/MMEL Fault) on flights previous to the accident flight.[58] It should be noted that the "ESCV Solenoid Wrap Fault" and "ESCV Demand Close/Switch Open" faults are known conditions, and are expected faults that result from a mismatch between the ESCV hardware and the ECU software (e.g. the software has not been changed to match the existing hardware).

Technically, no faults were recorded on the accident flight from the No. 3 engine ECU. However, status words in the NVM fault discretes indicate FMV (Fuel Metering Valve) and VSV (Variable Stator Vane) loop failures along with Group 1 FADEC Test and ARINC Wrap faults. Normally these faults would trigger snapshot data in the class 1 and 2 fault zones. Since these faults take additional time to be processed, it is believed that the ECU on engine number 3 either lost alternator power, or the engine core speed (N_2) spooled down too rapidly for the faults to be isolated with their snapshot data. This could indicate that the damage to engine Number 3 or its FADEC was more rapid or severe than to the other engines.

S/N ECDD6071 (Engine No. 2) ECU recorded a trend of "ESCV Demand Close/Switch Open" faults on Channels A and B; on Channel B it also recorded a trend of "LPTC LVDT" faults (both classified as Dispatchable Fault-Other Maintenance Items or Aircraft EAD/MMEL Fault). These faults were logged on flights previous to the accident flight and on the accident flight itself. Multiple additional faults were logged on both channels beginning at 05:32 UTC on 7/31, the date and approximate time of the accident. Some faults record "snapshots" of

[57] CF6-80C2DF FADEC Turbofan Engine Control System Time Limited Dispatch Summary for MD-11 (Revision 5)

[58] ESCV=Eleventh Stage Cooling Valve

engine and air data as described above. Other faults do not record the snapshot parameters, but do record date and time (UTC). The accident flight leg for Channel A was leg 43; on Channel B it was leg 42. The tables below illustrate the No Dispatch Faults on the accident flight (logged at about the time of the accident) for both channels, with some of (but not all of) the "snapshot" data associated with those faults. It should be noted that, with the exception of date and time, the FADECs do not rely on ship's power to generate and store faults and the associated data.

FADEC 6071 Channel A "No Dispatch" Faults on Accident Flight					
Fault (Flt Leg)	**Date**	**Time UTC**	**T495 (EGT)**	**Mach No.**	**TAT °C**
T25 RTD (43)	07/31	05:32	544	0.16	26
T12 RTD (43)	07/31	00:00*	528	0.14	27
VSV Pos/Demand (43)	00/00*	00:00*	464	0.08	27
*The FADEC receives time and date information from aircraft systems. The loss of date and time information is consistent with a loss of communication between the FADEC and aircraft systems.					

FADEC 6071 Channel B "No Dispatch" Faults on Accident Flight					
Fault (Flt Leg)	**Date**	**Time UTC**	**T495 (EGT)**	**Mach No.**	**TAT °C**
TLA Resolver (42)	00/00*	00:00*	464	0.08	27
VSV Pos/Demand (42)	00/00*	00:00*	448	0.06	27
*The FADEC receives time and date information from aircraft systems. The loss of date and time information is consistent with a loss of communication between the FADEC and aircraft systems.					

S/N ECDD6834 (Engine No. 1) ECU recorded a trend of "ESCV Solenoid Wrap" faults on Channel A, and "ESCV Demand Close/Switch Open" faults on Channel B. Channel A recorded a No Dispatch Fault, TLA Resolver, which was stored in memory but date, time, and flight leg data for this fault recorded zeros. Because zeros start to be recorded during the accident in other data, it is believed that this fault was logged during the accident sequence after loss of the ARINC signal from the aircraft. Multiple additional faults were logged during the accident flight on Channel B beginning at 05:32 UTC. The Channel B accident flight leg was leg 26.

FADEC 6834 Channel B "No Dispatch" Faults on Accident Flight					
Fault (Flt Leg)	**Date**	**Time UTC**	**T495 (EGT)**	**Mach No.**	**TAT °C**
VSV Torque Motor Wrap (26)	07/31	05:32	000	0.42	51
VBV Torque Motor Wrap (26)	00/00*	00:00*	000	0.39	23
FMV Torque Motor Wrap (26)	00/00*	00:00*	000	0.39	23
*The FADEC receives time and date information from aircraft systems. The loss of date and time information is consistent with a loss of communication between the FADEC and aircraft systems.					

A review of the troubleshooting information for the faults indicates that open or shorts in cables or windings, or loose connectors, are some of the more consistent causes for these faults. This would support hardware damage during the accident sequence as the most likely source of the logged faults.

GE has indicated that care should be exercised in interpreting the engine performance values stored during the accident sequence: while some values appear to be accurate, others, such as engine speeds, appear to be inconsistent with the DFDR data.

1.14.2 Loads and Structural Analyses

Since the results of the detailed examination of the recovered accident parts indicated no preexisting condition (fatigue, defect, dimensional discrepancy, etc.) that could have contributed to the failure of the landing gear or wing components, BLBD used existing computer models of the landing gear and wing structure to investigate the loads generated and distributed into the aircraft structure during the accident sequence. The in-house models included the G4TA model for main landing gear loads distribution analysis, the B7DC model for dynamic main landing gear ground loads analysis, and the CASD model for internal loads and structural analyses. These computer models were originally used for aircraft certification purposes. The NASTRAN model was used for initial dynamic structural analysis, followed by the ADAMS (Automatic Dynamic Analysis of Mechanical Systems) model for the generation of more rigorous dynamic structural analyses. Information developed from the FDR data, ground scars, and examination of failed structural components, as well as known aerodynamic and structural characteristics of the aircraft, were used for model input and/or to validate results.

Descriptions of all these models and their initial results were previously supplied to the NTSB and parties to the investigation during a meeting at BLBD in March of 1998. This submission will focus primarily on the most recent results achieved with the ADAMS model analysis.

1.14.2.1 ADAMS Model Analysis

In an effort to better understand the loads, deflections, and sequence of component failure, BLBD applied the ADAMS simulation tool to the events of the accident. The ADAMS software, a product of Mechanical Dynamics, Inc. (MDI) of Ann Arbor, Michigan, provides a dynamic, time domain response from highly complex and non-linear mechanical models.

Initial simulations with the ADAMS software were based on elastic axis beam and lumped mass models of the MD-11's wing, rigid fuselage and empennage, landing gear (see Illustration 4 below), MD-11 aerodynamic characteristics, and flight recorder data from the accident aircraft. Results from these initial simulations, while useful, were not sufficiently detailed in the area of structural interest. These early results were shared with the NTSB and parties to the investigation during the March 1998 meeting in Long Beach, where it was generally recognized that the initial simulations were interesting, but more work needed to be done to improve the fidelity of the model.

Since the March meeting efforts have focused on improving the overall fidelity of the model and expanding the capability of the model to allow disconnecting of selected structural elements at predefined load levels. BLBD provided the whole aircraft dynamic model in the format of a highly detailed NASTRAN model, which MDI imported into ADAMS. As before, aircraft landing gear, aerodynamic forces, and flight recorder data were supplied by BLBD and were applied to the ADAMS model. The emphasis of the additional refinement of the ADAMS model was on accurately representing the behavior of the portion of the wing between the fuselage side-of-body and the landing gear attach fitting/bulkhead, the wing-to-fuselage connection, and the trap panel-to-sidebrace fitting connection. See Illustration 5. Fidelity of the model was validated by comparing ADAMS model output with output from previously-verified models (such as B7DC, G4TA, and NASTRAN) at loads within the design range.

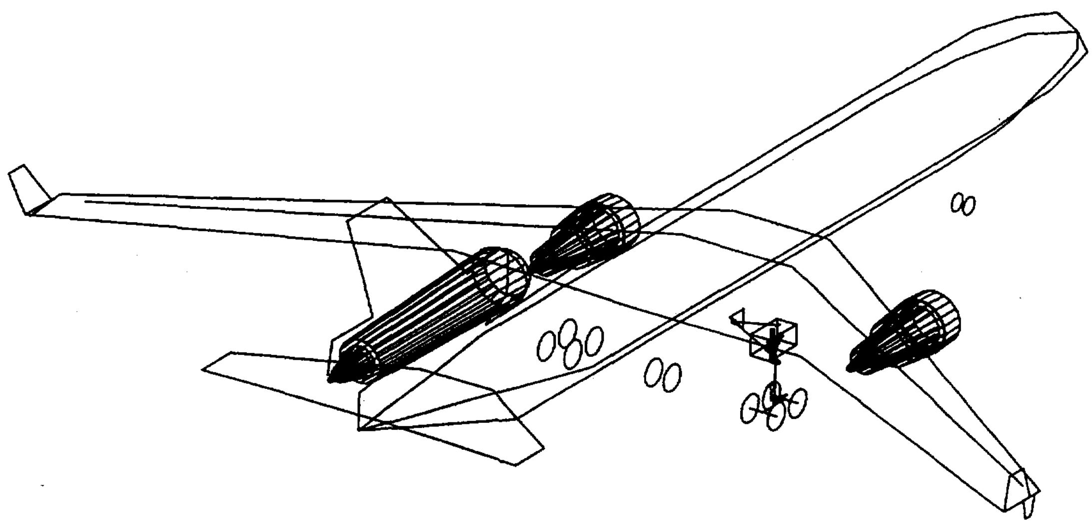

Illustration 4
Initial ADAMS Model

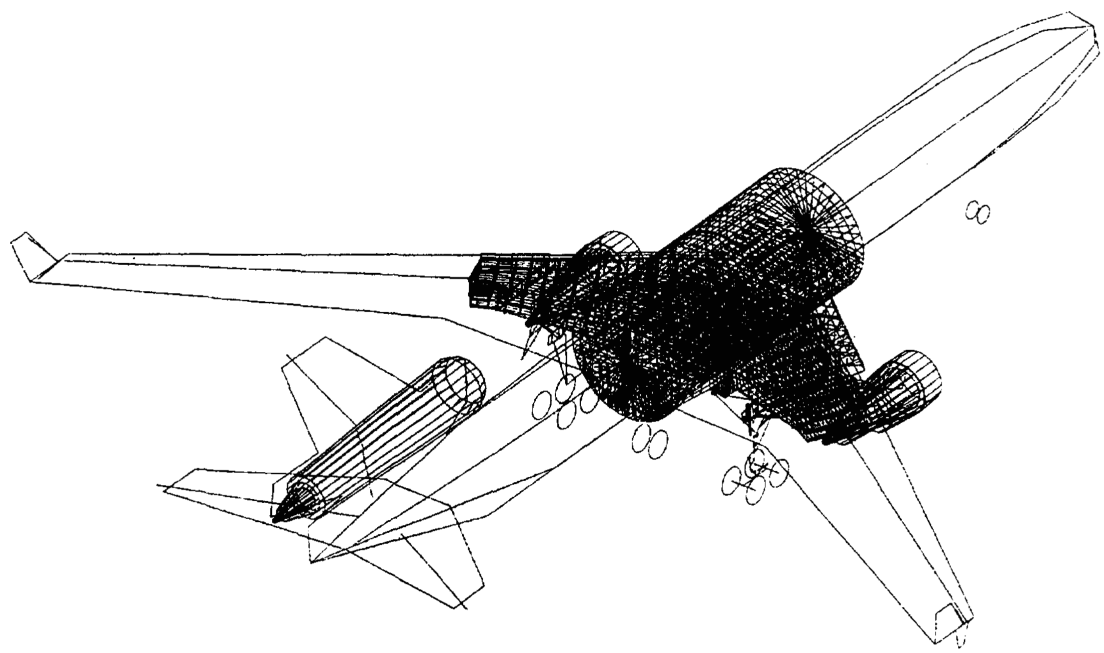

Illustration 5
Revised ADAMS Model

The results of the ADAMS analysis are included in the Analysis section of this report.

1.14.3 Additional Information

1.14.3.1 Tire Failure Alert

The latency (time delay) between a tire failure and the associated Central Aural Warning System (CAWS) callout should not exceed approximately 1.24 seconds (1240 milliseconds), assuming no power transients. This delay is due to:

1. The Brake Temperature Monitor/Tire Pressure Indicator (BTM/TPI) unit, powered by the No. 3 28-Volt DC bus, takes a maximum of approximately 468 milliseconds (ms) to detect a tire failure and another 468 ms to confirm the failure. Processing the information takes another 2 ms and time to output a signal to the Central Aural Warning System (CAWS) takes an additional 2 ms.

2. When the CAWS receives a signal from the BTM/TPI, the input signal is verified to be valid by requiring the signal to exceed 200 ms in duration. Once the signal has been validated it takes another 100 ms to generate an annunciation.

The "tire failure" aural warnings are provided in sets of three aural annunciations and repeat until cancelled. Each aural annunciation of the words "tire failure" is 1 second in duration; the interval between annunciations one and two, and between two and three, is 200-300 ms each; the interval between the end of the third "tire failure" annunciation in the first set and the beginning of the first "tire failure" annunciation in the next set is 700-800 ms.

If the BTM/TPI computer was exposed to a power loss of less than 10 ms the BTM/TPI computer would continue to operate. If the BTM/TPI computer was exposed to a power interruption lasting more than 10 and less than 250 ms, the computer would perform a "warm start" lasting approximately 200 ms. If the BTM/TPI computer was exposed to a power interruption lasting more than 250 ms, approximately 6 seconds would be required to perform a "cold start".

If there were a power loss to the CAWS lasting less than 200 ms, the CAWS unit would continue to operate. If there were a power interruption of greater than 200 ms to the CAWS, it would take from 250 to 500 ms for the CAWS to return to operation. The tire failure warning portion of the CAWS is powered by the No. 1 28-Volt DC bus.

1.14.3.2 Right Inboard Flap Separation

The accident aircraft's right inboard flap section came to rest on taxiway H (Hotel)[59] approximately 452 ft. beyond the beginning of the second touchdown impact tire marks.[60] Since the aircraft rolled to the right between the first and second touchdowns, flight recorder data were analyzed to determine if the right inboard (RIB) flap segment departed the aircraft prior to second touchdown impact. The last FDR recorded position of the RIB flap was 50° at subframe 343 (at the first touchdown).

The FDR-recorded control surface deflections were input into a desktop version of the FAA-qualified Level D MD-11 simulation at BLBD facilities in Long Beach. Flap loss was simulated by immediately retracting the RIB flap from 50° to 0° at subframes 343.5 (0.5 seconds after the first touchdown), 344, 344.5, 345, and 345.5. Additionally, a "no RIB flap loss" prior to subframe 346 simulation was run. Only the "no RIB flap loss" simulation resulted in an aircraft response similar to the accident flight FDR data. Every other case resulted in greater roll angles

[59] Structures Group Chairman's Factual Report of Investigation, Wreckage Distribution Diagram.
[60] Airplane Performance Study, page 4.

than were recorded during the accident (see Appendix 5.4 for a plot of the simulations).

1.14.3.3 BLBD-Recommended Landing Technique

The BLBD-recommended landing techniques outlined in the Know Your MD-11 Letter No. 3, dated 14 April, 1993, were distributed to all MD-11 operators (see Appendix 5.5). On page two of the letter, under the paragraph heading "Flare", are the following words:

> "Auto throttles will begin to retard after passing 50', and a slight flare should be initiated between 30 and 40 feet (approximately 2°). The aircraft should touch down in the touchdown zone. The technique described above will result in a touchdown slightly below V_{ref}. Do not hold the aircraft off ...."

The above technique was reiterated during the 1993 BLBD MD-11 Flight Operations Seminar topic Landing Techniques, presented on October 28, 1993 (see Appendix 5.6), at which representatives from FedEx were in attendance. The summary of the Landing Techniques presentation is listed below:

- Stabilize Speed—Use Autothrottles
- Stabilize Flight Path—Use Flight Director (or Autopilot)
- Maintain Descent Through 50 and 40 Foot Callout Unless Sink Rate Is High
- Flare With 2.5° of Pitch Change at 30 Feet
- Arrive Below 10 Feet Flared. Then Relax Back Pressure to Touchdown
- Continue Forward Control Column Pressure After Touchdown to Gently Lower Nose Wheels to the Runway and Avoid Pitchup

The MD-11 Flight Crew Operating Manual (FCOM) recommends:

> "Below 10 feet with the aircraft fully flared (sink rate approximately 2-4 feet per second), the basic technique is to maintain attitude by applying the required control wheel pressures. A more advanced technique is to actually begin lowering the nose (approximately 1°) prior to main gear touchdown."

In summary, the recommended technique calls for a small nose-up pitch change (approximately 2°) initial flare followed by, at the PF's option, an approximately 1° nose-down pitch change when below 10 feet AGL.

1.14.3.4 BLBD-Recommended Go-Around Initiation

On page 4 of the above-referenced Know Your MD-11 Letter, under the additional guidelines section, item 3 states:

> "Experience has shown that approaches which result in large pitch deviations, and which never achieve true speed and glide path stability are much more likely to produce unpredictable landings; hold-offs, floats, hard touchdowns, strong rebounds and tailstrikes. Such approaches make it nearly impossible to establish a proper crosswind correction, and are especially risky on contaminated or slippery surfaces. ***A destabilized approach is a compelling reason to initiate an early go-around***" (emphasis added).

The MD-11 FCOM also states: "Aircraft should be stabilized in final landing configuration, on descent flightpath, and on speed with appropriate wind and gust corrections applied to V_{REF} by 1000 feet AGL. If aircraft is not stabilized by 500 feet AGL, a missed approach should be executed......"

1.14.3.5 FedEx High Sink Rate and Bounce Recovery Technique

Quoting from the FedEx "High Sink Rate and Bounce Recovery Technique" section of their "MD-11 Tail Strike Awareness Information" bulletin:[61]

> "The recommended high sink rate and bounce recovery technique is to establish a 7 ½ degree pitch attitude and arrest the sink rate with thrust. If a high bounce occurs, a go-around should be initiated. Low-level go-arounds, i.e. less than 20 feet RA, are dramatically different than higher-altitude go-arounds. High altitude go-arounds are initiated with pitch, while low level go-arounds must be initiated with thrust. During low level go-arounds main wheel touchdown may be unavoidable. The PF must not exceed 10 degrees of pitch or retract the landing gear until passing 20 feet RA with a positive rate of climb.
>
> "Some tail strikes have occurred as a result of the pilot attempting to arrest a high sink rate or bounce by quickly adding up elevator. This technique immediately increases both the effective weight of the aircraft and the aircraft's vertical velocity. The resulting increased attitude rate will aggravate the pitching tendency after touchdown and drive the main wheels into the ground, thus compressing the main wheel struts. The aft fuselage will contact the runway at approximately 10 degrees pitch attitude with the struts compressed.

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[61] Group Chairman's Factual Report Operations/Human Performance Group, Attachment 3, page 4

"It is imperative that pilots fully understand the correlation between an increasing attitude rate at touchdown and an increased pitch up tendency after touchdown. One degree per second of increasing attitude rate at touchdown generates as much pitch up tendency as full spoiler deployment. Elevator back pressure should be relaxed, and a constant pitch attitude should be maintained from 10 feet radio altitude to touchdown."

1.14.3.6 Landing Gear Energy Absorption And Overload Certification

FAR (Federal Aviation Regulations) paragraphs 25.723 (a), (b), 25.725, and 25.727 define the landing gear energy absorption certification requirements. The MD-11 landing gear show compliance to these conditions by analysis supported by drop tests done on DC-10 landing gear (which are almost identical to the MD-11 landing gear).

FAR paragraphs 25.723 (a) and 25.725 address the limit landing conditions where 10 fps is considered the limit descent velocity at maximum design landing weight, and 6 fps is considered the limit descent velocity at maximum design take off weight per FAR 25.473. FAR paragraphs 25.723 (b) and 25.727 address the landing gear reserve energy absorption capacity requirements and is considered an ultimate design condition. Per these FAR paragraphs the landing gear may not fail up to a descent velocity of 12 fps at maximum design landing weight.

Tests and analyses performed to show compliance to the above FAR paragraphs assume that the aircraft lift is equal to the aircraft weight during landing per FAR 25.473 (2) and 25.723 (b).

The MD-11 landing gear also is certified to the FAR 25.721 (Amendment 61) landing gear overload requirements. FAR 25.721(a)(2) defines the certification requirements for overload conditions that may occur during take-off and landing. Because a review of the available historical data indicated that main landing gear failure due to overload was most likely to occur as a result of striking an obstruction, BLBD believed that the most probable condition would be 1.0 g vertical gear load at maximum ramp weight (i.e. the weight of the aircraft would be distributed between the two main landing gear, the center main landing gear, and the nose landing gear with no aerodynamic lift; for a 628,000 lb. ramp weight aircraft this vertical load is 257,000 lb. per outer main landing gear), static gear extension, with a drag load applied to the axles until the failure of the gear. For this condition it was shown by analysis that the main landing gear would separate from the wing without any failures to the fuel tanks. This was validated by tests done on full-scale DC-10 landing gear and wing test structure. By analysis this was shown to be true for vertical loads up to 2.0 g's (i.e. twice the weight of the aircraft is distributed between the two main landing gear, the center main landing gear, and the nose landing gear with no aerodynamic lift; for a 628,000 lb. ramp weight aircraft this vertical load is 514,000 lb. per outer main landing gear) at the aircraft maximum ramp weight.[62]

Because a fuse in the vertical plane may not prevent substantial loads from entering the wing structure once the fuse has released, and because the review of historical data indicated that failure due to overload was most likely to occur as a result of high drag loads, a different approach was taken to assure fuel tank integrity for the high vertical load (above 2.0 g's) condition. For vertical loads above 2.0 g's the main landing gear is not designed to separate from the wing. Instead, the landing gear and its back-up structure are designed to be very robust, i.e. they are designed to withstand significantly larger descent rates than the 12 fps (ultimate) required per FAR 25.723 (b). Analysis has indicated that for a maximum landing weight, typical-landing-configuration landing, the MD-11 main landing gear can withstand up to a 16.9 fps descent rate without bottoming the shock struts and tires or failing its backup structure (including the wing rear spar). Similarly, for a rolled landing (8 degrees one-wing-low attitude, with lift equal to aircraft weight), the landing gear can withstand up to a 15 fps descent rate without bottoming the shock strut or failing its backup structure including the wing rear spar.[63]

1.14.3.7 Previous Wide Body High Vertical Load Landing Accidents

To provide a comparison of this accident with previous wide body high vertical load landing accidents, brief descriptions of 2 hull loss events are provided below. The NTSB participated in the investigations into the accidents, as U. S. Accredited Representative on the Faro DC-10 and as the investigating authority on the JFK L-1011. Both accidents occurred after the MD-11 had been certified and had entered revenue service.

1.14.3.7.1 Martinair DC-10-30CF Accident, Faro, Portugal

On 21 December 1992 a Martinair DC-10-30CF, operating as an early morning passenger flight from Amsterdam to Faro, Portugal, crashed during landing at Faro. There were 56 fatalities among the 340 passengers and crew, and 106 serious injuries. The aircraft was destroyed by impact forces and post-impact fire. The accident occurred during the hours of darkness and while a thunderstorm was in progress at the Faro airport. The Faro airport does not have

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[62] The loads developed during this accident on the right main landing gear (RMLG) exceeded the main landing gear bottoming load of approximately 600,000 lb.

[63] The loads developed during this accident on the RMLG (from both a descent rate at the RMLG of 13.5 fps--which was calculated from a combination of the aircraft's descent rate at its center of gravity and its roll rate--and greatly reduced wing lift) exceeded the 600,000 lb. strut bottoming load by a minimum of approximately 107,000 lb. (a vertical ground load at the RMLG of approximately 707,000 lb. is required to fail the rear spar shear web).

precision instrument approaches; the accident flight had flown a VOR approach upon arrival at Faro.

The investigation into the accident was accomplished by the Portuguese government, with assistance from the operator, the Netherlands Accident Investigation Bureau, the NTSB, the FAA, BLBD (then Douglas Aircraft Company), and others. The final report of the accident investigation was produced by the Portuguese government and translated into English by the Netherlands Aviation Safety Board.

The investigation revealed that the DC-10 landed approximately 6° right wing down at approximately 17 fps (including RWD roll rate), and at a yaw angle (relative to the runway heading) of about 7° ANR. The RMLG collapsed inboard but did not separate; the right inboard flap segment separated from the aircraft at or shortly after touchdown; the engine nacelle and wingtip struck the runway; and the right wing separated from the aircraft between the fuselage and the engine. The outboard right wing tip did not fail. Recorded vertical acceleration at the beginning of the landing was approximately 1.1 g; maximum recorded vertical acceleration during the touchdown was approximately 1.95 g. See Appendix 5.7 The aircraft rolled inverted after wing separation and the fuselage broke into three sections; the sections rolled upright again (except for the forward section, which rolled onto its left side) after leaving the runway surface.

The final report did not provide detailed RMLG or wing failure data, sequential failure data, or wreckage distribution/runway markings diagrams. The right wing trapezoidal panel area was not documented.

In Section 3 of the report *(Conclusions)*, it was noted that "The premature power reduction and the sudden wind variation probably increased the rate of descent, which reached values exceeding the operational limits of the aircraft." Also noted was "The fracture of the right main landing gear was due to the combination of the high rate of descent and the drift correction taking place at the moment of contact with the runway." Under *Causes* the report reads:

> "The commission of inquiry determined that the probable causes for the accident were:
>
> - The high rate of descent in the final phase of the approach and landing made on the right landing gear, which exceeded the structural limitations of the aircraft.
> - The crosswind, which exceeded the aircraft limits and which occurred in the final phase of the approach and during landing.
>
> The combination of both factors determined (sic) stresses which exceeded the structural limitations of the aircraft."
>
> "Contributing factors to the accident were:

- The instability of the approach.
- The premature power reduction, and the sustaining of this condition, probably due to crew action.
- The incorrect wind information delivered by Approach Control.
- The absence of an approach light system.
- The incorrect evaluation by the crew of the runway conditions.
- CWS mode being switched off at approx. 80 ft RA, causing the aircraft to be in manual control in a critical phase of the landing.
- The delayed action of the crew in increasing power.
- The degradation of the lift coefficient due to the heavy showers."

1.14.3.7.2 TWA L-1011 Accident, JFK, New York, 30 July 1992

The TWA L-1011, which was taking off at just under its maximum allowable takeoff weight of 430,000 pounds, rejected takeoff after becoming airborne due to a stall warning indication. The aircraft touched down, 1.1° right wing down, at a sink rate of approximately 14 fps while nearly 71,000 lb. over maximum gross landing weight (358,000 lb.). The landing fractured the right wing aft spar between the RMLG and the fuselage. The wings and landing gear did not separate from the aircraft; however, the aircraft was destroyed by post-impact fire.

Witnesses observed fuel, mist, or debris escaping from the underside of the airplane or right wing at or just after touchdown. Most witnesses said that fuel escaped and ignited soon after the airplane touched down. Fire was observed travelling along the fuselage on the right side.[64]

The recorded vertical acceleration at the start of touchdown impact was approximately 0.75 g; peak vertical acceleration during touchdown impact was approximately 1.9 g. See Appendix 5.8.

In the *Conclusions* section of the NTSB's report, Finding 11 stated that "The first officer either pushed the control column forward or allowed the control column to move forward in reaction to the false stall warning." These actions account for the 0.75 g vertical acceleration recorded by the aircraft's flight recorder at the beginning of the touchdown impact.

Finding 13 of the NTSB's report stated "The airplane landed extremely hard at a vertical descent rate of about 14 feet-per-second (sic), considerably over the maximum structural design limit of 6.0 feet-per-second, and at a weight of about 71,000 pounds over the design maximum landing weight." It should be noted that the 6 feet per second design condition is for landings at weights over

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[64] NTSB-AAR-93/04

maximum allowable landing weight but not exceeding maximum allowable takeoff weight.

Finding 14 of the NTSB's report stated "The airplane was in a slight right-wing-low attitude when the right main landing gear touched down first, near the runway centerline crown. The right main landing gear touched down at a force exceeding the structure design limits, resulting in overload fractures in the right wing rear spar; no evidence of fatigue was found in the fractures."

The NTSB's probable cause statement for the L-1011 accident was: "The National Transportation Safety Board determines that the probable cause of this accident were design deficiencies in the stall warning system that permitted a defect to go undetected, the failure of TWA's maintenance program to correct a repetitive malfunction of the stall warning system, and inadequate crew coordination between the captain and first officer that resulted in their inappropriate response to a false stall warning."

2 ANALYSIS

2.1 GENERAL

The aircraft was certified to, and met or exceeded, all applicable FAA requirements.

The factual data indicate that, with the exception of the inoperative thrust reverser and left landing light, the aircraft and its systems were functioning normally up to the point of second touchdown impact. The autobrakes armed normally for takeoff out of Anchorage and for landing at Newark. All observed primary structural fractures were the result of overload.

Newark's longest runway (22L) was closed at the time of the accident.

The condition and potential operability of the L1 and deactivated passenger entrance doors immediately after the aircraft came to rest is not known.

Weather, communications, and air traffic control were not factors in this accident.

The right inboard flap remained attached to the aircraft until or just after second touchdown impact, and was not a contributor to the right wing down roll attitude at the second touchdown.

The flight control and throttle inputs during the accident sequence resulted from pilot inputs, since 1) the autopilot was disconnected, 2) LSAS was inactive, and 3) the maximum rate at which the autothrottles can advance or retard the throttles is 8° per second. The recorded flight control inputs during the landing sequence were both contrary to and in excess of published BLBD-recommended landing technique inputs.

A go-around, executed at the moment the pilot believed the approach had become destabilized (i.e.. when he believed that large elevator and throttle inputs were necessary), would have been consistent with published BLBD-recommended procedure.

The control inputs just prior to the first touchdown, and between the first touchdown and second touchdown impact, were not consistent with FedEx's "High Sink Rate and Bounce Recovery Technique" recommendations.

2.2 POST-IMPACT TIRE FAILURE ALERT

Normally functioning (i.e. operational with no power interruptions) BTM/TPI and CAWS systems should have generated a "tire failure" alert within approximately 1.24 seconds of a tire failure. Since the aural "tire failure" alert did not sound until approximately 4.43 seconds after second touchdown impact, either the #4 tire did not fail precisely at impact, or there may have been multiple short-duration power transients affecting the BTM/TPI and/or CAWS units. Evidence indicates that the "tire failure" alert may have been interrupted prior to the end of the CVR recording, as the beginning of the third "tire failure" voice annunciation should have been (but apparently was not) recorded on the CVR. That evidence, coupled with the 0.31 second loss in audio on the CVR and the approximately 1.3 second data dropout in the FDR, indicates that multiple short-duration power transients could have occurred, and these transients in turn could have delayed the generation of the CAWS "tire failure" warning.

2.3 NVM DATA

The faults recorded in NVM prior to the accident are minor in character and indicate a normally functioning aircraft up to the time of second touchdown impact. The faults recorded at the time of impact are consistent with power interruption(s) and/or unusual aircraft motion in the pitch and roll axis; some of the recorded faults have also been seen before on previous MD-11 hard landing events.

Questions arose during the investigation concerning the LSAS system and whether it was possibly active during the accident landing.

It can be concluded that LSAS was inactive below 100 feet during the accident landing sequence because:

1. The UFDR did not record any LSAS faults during the accident landing; and
2. According to the certification Failure Modes and Effects Analysis (FMEA), the only failure that would prevent LSAS from "washing out" within one second of passing below 100 ft. radio altitude is a failure of the radio altitude systems such that they would output an altitude signal above 100 ft. to the FCCs. All available data indicate that the radio altimeters (RAs) were functioning normally during the accident flight and landing sequence. Specifically, the UFDR trace indicated that the autothrottles retarded as the aircraft descended below 50 ft. radio altitude; both radio altitude parameters recorded rational altitude data through the first and second touchdowns; the aural "1000, 500, 100, 50, 40, 30, 20, 10" radio altitude callouts were heard on the CVR[65]; and

[65] CVR transcript, pp. 34-35.

the only FCC-logged RA fault occurred after second touchdown impact[66]. There is only one known "undetected" (by the radio altimeter) RA failure mode, and this mode would result in a lower radio altitude signal to the FCCs than the actual radio altitude. The net effect would be that LSAS would actually "wash out" at a higher altitude than had the RA been functioning normally. This particular failure would also generate a split radio altitude fault that would be logged by the FCCs; no such fault was logged in the FCC fault data.

2.4 FARO, JFK, AND NEWARK ACCIDENTS

The Faro DC-10, JFK L-1011, and Newark MD-11 accidents all involved high energy in the vertical plane at touchdown. In the Faro DC-10 accident, the vertical energy was the result of premature reduction in engine thrust, an unstabilized approach, and gusting wind conditions. In the L-1011 accident, the vertical energy was the result of an AND "push-over" response to a (false) stall warning indication, and possibly the pilot's need to get the airplane on the ground so that the rejected takeoff could be completed. In the Newark accident, the vertical energy was the result of an AND "push-over" by the pilot apparently attempting to avoid a tailstrike and/or to "plant" the aircraft on the runway so that wheel braking could be initiated. The common denominator in all these accidents is the high vertical energy. The process and/or conditions by which the energy developed was to some degree different in each of the three accidents. In both the L-1011 and Newark accidents, however, a vigorous AND control input was made while the aircraft was very close to the runway surface and while the pilots' attention was focused outside the aircraft.

The NTSB has asked for Boeing recommendations for additional pilot information, training, display information, etc. that may help to prevent future accidents similar to the Newark, Faro, and JFK accidents.

In the Faro accident scenario, the availability of a precision Instrument Landing System (ILS) approach would have provided much better vertical (and horizontal) guidance to the runway than the VOR approach, and would have made it easier to stabilize the aircraft during the approach. In Boeing's opinion, airports routinely served by transport category aircraft should be equipped with ILS approaches.

In situations where the pilot has the time to observe and react to information displayed either in the cockpit or on a Heads Up Display (HUD), some forms of instrumentation may be helpful in preventing high aircraft sink rates or low energy states from developing. For example, Boeing is in the early stages of research and development on a Vertical Situation Indicator, which is intended to assist the flight crew in obtaining and maintaining awareness of their vertical situation, and

[66] The airspeed logged at the time the fault occurred was lower than the airspeeds recorded during the first and second landings.

could assist the crew in flying a stabilized approach. Some operators, such as Alaskan Airlines and American Airlines, are currently installing HUDs on many of their aircraft. BLBD offered HUDs on our MD-80 aircraft, however, few operators chose to purchase that option.

In cases where the unsafe situation is unfolding rapidly and the airplane is very close to the ground, leaving little time to look for, assimilate, and react to displayed information, such as in the JFK and Newark accidents, it is, in Boeing's opinion, doubtful that any additional or different information display technologies would help prevent an accident from occurring. Instead, training to avoid the situation in the first place remains the best bet for prevention, with emphasis during the training given to recognizing developing approach situations which may place the airplane at risk, and how a proactive go-around policy can be of value. A pilot must be mentally prepared to execute a go-around if the flight path becomes unstable for whatever reason, including pilot inputs.

The Boeing and Douglas companies have stressed for many years the critical importance of flying a stabilized approach, including specific guidance on what constitutes such an approach, and when to execute a go-around. Attempting to quantify "structural loading factors such as high sink rate, excessive downward vertical acceleration due to excessive nose-down elevator inputs, etc." would not, in our view, provide the pilot with anything that would be of practical use, other than in a general sense, as the crew has no way to measure such criteria. The emphasis in training should include helping the crew develop techniques that prevent the aircraft from getting into a critical situation in the first place, and if there, how to recognize it and then get out of it. Boeing is a strong and enthusiastic supporter of the Flight Safety Foundation's Approach and Landing Accident Reduction (ALAR) task force activities along these lines.

Additionally, go-around criteria should be provided not only to flight crews, but provided to (if not already) Air Traffic Control (ATC) personnel and airline management as well. A pilot's reluctance to go-around may be attributable to several factors, therefore, as a means to help overcome that reluctance, flight crews should be encouraged by company policy to perform proactive go-arounds at their discretion. Further, while recognizing that unexpected go-arounds could increase ATC's workload, and have resulted in ATC's occasional impatience with the disruptive effects on traffic flow, the flight crew's top priority remains the safe operation of the aircraft.

Accident and incident data indicate a periodic or cyclical nature to the frequency of tailstrikes, hard landings, hard nosegear touchdowns, etc. over time. It would therefore appear that operators could benefit from establishing periodic awareness, recognition, and recovery training associated with the above landing difficulties. Boeing recognizes that many operators have already established such training programs; those that have not may want to consider doing so.

2.5 ESTIMATED ENERGY DISSIPATED INTO THE LANDING GEAR DURING SECOND TOUCHDOWN IMPACT

Since kinetic energy is a form of energy associated with the motion of an object, the kinetic energy dissipated into the landing gear during landing touchdown is derived from both the rate of descent and the aircraft's rolling rate at touchdown, and is commonly expressed by the formula $K = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$ where M = mass, v = velocity, I = rolling moment of inertia, and ω = aircraft roll rate. Potential energy, commonly expressed as U = Mgh where g = gravitational acceleration and h = vertical distance above a reference level, is the energy associated with the relative position of an object. If gravitational force acts upon an object imparting movement in that object, then potential energy is converted to kinetic energy. In 1.0 g stabilized flight, aircraft weight is counteracted by wing lift (lift = weight = mass x 1.0 g), resulting in a net vertical acceleration of 0. Therefore, when the aircraft is at 1.0 g flight (lift = weight), potential energy is zero (because net vertical acceleration on the mass M in the equation U=Mgh is zero). During a normal landing the kinetic energy from descent and roll rates is absorbed by shock strut stroking at touchdown, which can be called "Phase 1" energy absorption. Then, during "Phase 2" energy absorption (also by shock strut stroking), potential energy related to aircraft weight eventually gets absorbed by the main and nose landing gears as wing lift is reduced due to the reduction of both angle of attack and forward velocity, and deployment of ground spoilers. This energy is normally absorbed some time after the total kinetic energy related to the descent rate is completely absorbed at initial touchdown. See Appendix 5.9 for a more detailed description of kinetic and potential energy as applied to landing gear energy absorption.

In a stabilized approach, assuming calm atmospheric conditions and ignoring ground effect, once the aircraft's rate of descent is stabilized, vertical acceleration is equal to 1.0 g and lift is equal to the aircraft weight. If a flare is not initiated under these conditions, the resulting vertical loads of the landing gear would be solely due to the rate of descent of the aircraft at touchdown, i. e. from the aircraft's kinetic energy, as wing lift is exactly countering the weight of the aircraft (Mg), which results in zero potential energy that needs to be absorbed by the landing gear.

If a "flare" of, for example, 0.1 g (lift = 1.1 g x mass) were initiated and held, the kinetic energy from the rate of descent of the aircraft would be decreased by the work performed by the aircraft's increased wing lift. Although the foregoing is a bit oversimplified, this is exactly why aircraft are flared prior to landing: to trade relatively small increased lift loads into the entire wing structure for greatly reduced energy point loads into the landing gear and associated attaching structure.

The opposite also holds true. If the aircraft's vertical acceleration at touchdown is a value less than 1.0 g, then the energy that results from the positive acceleration towards the ground due to the reduced lift becomes additive to the kinetic energy from the rate of descent. The effect is that the landing gear has to absorb not only the "Phase 1" energy at touchdown, but a portion of the "Phase 2" energy at the same time. The end result is a higher load into the landing gear and attaching structure during touchdown.

The accident aircraft's recorded vertical acceleration at the start of second touchdown impact was approximately 0.5 g, that is, wing lift was equal to approximately half the aircraft weight, which imparted huge additional potential energy into the landing gear and attaching structure *above and beyond those associated with the 11 fps center of gravity descent rate and the 7 deg./sec. roll rate.* In addition, these energies were imparted primarily into the RMLG only, due to the right wing down roll angle (8°-10°) at touchdown. At the accident aircraft's landing weight of 452,000 lb., at lift = 0.5 g x mass, as described in Appendix 5.10, potential energy of 678,000 ft.-lb. was added to the approximately 896,000 ft.-lb. RMLG kinetic energy from the combined aircraft descent and roll rates, for a total energy into the RMLG of nearly 1,574,000 ft.-lb. Comparing the loads into the RMLG from the accident landing at Newark to the RMLG energy absorption requirements for certification shows that the energy developed during the accident landing was over *3 times the reserve energy (ultimate) certification requirements for a single main landing gear.*

Applying the same kind of analysis to the Martinair DC-10-30 accident at Faro (also described in Appendix 5.10), at a landing weight of 353,000 lb., lift at start of touchdown of approximately 1.1 times the aircraft weight, and descent rate at the aircraft center of gravity of approximately 15 fps and roll rate of 6 deg./sec., the kinetic energy, 1,259,300 ft.-lb., was <u>decreased</u> by potential energy (from increased lift) by approximately 106,000 ft.-lb., for a total energy of approximately 1,153,000 ft.-lb. on the RMLG. Comparing the Faro accident energy with the DC-10-30's RMLG energy required for certification shows that the energy developed during the Faro accident landing *was over 2 and a half times the reserve energy (ultimate) certification requirements for a single main landing gear.*

In terms of energy dissipated into the landing gear, the 11 fps descent rate Newark touchdown impact was a more severe test of the landing gear and aircraft structure than the 15 fps descent rate Faro accident.

Similar analysis of the TWA L-1011 landing, in which the right wing rear spar fractured and the aircraft was destroyed by post-impact fire, estimated that the total vertical energy developed during the L-1011 right-wing-low accident touchdown was just over 2 times the certification requirements (Appendix 5.10). It is interesting to note that the 0.25 g nose-down "push-over" (1.00 g minus 0.75 g at start of accident touchdown) during the L-1011 accident was only half of the 0.50 g nose-down "push-over" (1.00 g minus 0.50 g at start of second touchdown impact) during the Newark accident.

2.6 ACCIDENT STRUCTURAL FAILURE SEQUENCE

During the course of the investigation two structural failure sequence theories were explored. The first theory, while consistent with much of the evidence observed and documented by the investigating teams, was inconsistent with other evidence in a few key areas, which ultimately lead to its rejection. The second theory appears to be a better match with the available evidence, and is, in BLBD's view, the more reasonable failure sequence.

Theory 1

The first structural failure sequence theory was reviewed in depth during the March 1998 meeting at Long Beach. The theory was (beginning at the second touchdown impact):

- the RMLG strut and tires bottomed;[67]
- right inboard flap separated;
- outboard bolt of the side brace fitting failed due to inboard load on the lower RMLG;
- RMLG swung outboard tearing inboard half of trap panel;
- RMLG trunnion arms struck wing attach fitting;
- RMLG separated from wing attach structure
    - forward trunnion bolt failed
    - wing fitting aft trunnion lugs failed
    - fixed side brace failed;
- load transferred to No. 3 engine and pylon;
- pylon fused, transferring load to outboard wing and flap;
- outboard flap failed at fuses; and
- wing failed inboard of the landing gear fitting.

As stated previously, the above sequence matched much of the available evidence, including the runway tire marks, engine No. 3 scrape marks, the burning fluid marks, the eyewitness accounts of the landing provided by the crew of the taxiing FedEx DC-10, the outboard wing and flap hinge failures, the No. 3 engine pylon failure, most of the failures/deformations of the landing gear bracing structure, and the damage to the RMLG attach fitting.

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[67] The failure of the RMLG truck beam is a secondary failure occurring downstream from the second touchdown impact. The function of the MLG trim cylinder is to maintain a right angle relationship between the truck beam and the piston for proper wheelwell clearance during landing gear extension and retraction cycles. Since the landing gear extended normally prior to landing it can be concluded that the trim cylinder was functioning properly prior to landing. The factual portion of this report noted that the angle between the RMLG piston and the truck beam was forcefully reduced well below the trim cylinder-maintained right angle in order for the truck beam fracture initiation site to align with the mating damaged eyebolt end of the trim cylinder piston. This reduced angle is inconsistent with angles that can be achieved with a normally operating trim cylinder.

However, Theory 1's biggest drawback was that there were no marks on the runway that corresponded to outboard right wing contact with the runway surface just after second touchdown impact. Other shortcomings included:

- the initial ADAMS model, using this theoretical sequence, could not generate sufficient loads at the trap panel to fail the side brace fitting bolt; and
- the lateral (outboard) acceleration needed to separate the right wing inboard flap section (roughly 2 g's) were not evident in the recorded data from the accident aircraft[68] or in the ADAMS simulation.

Because of the above-described shortcomings, an alternative structural failure sequence was explored and is described below.

Theory 2

Theory 2 differs from Theory 1 in that the initial structural failure in the sequence is the failure of the wing aft spar web, just inboard of the RMLG attach fitting. The shear load required to fail the spar web was the result of a large "punch" load imparted by the bottomed RMLG during second touchdown impact. The spar web failure led to the failure of the upper and lower rear spar caps, and to progressive failure (starting aft and moving forward) of the inboard wing upper and lower wing skins and stiffeners. The combined effect of these wing box failures caused significant local bending (wingtip up), and the wing (outboard of station 264) to twist significantly nose down.

This theory was simulated using a modified ADAMS idealization by analytically failing the inboard rear spar shear web at the appropriate load level. See Appendix 5.11, Figures 1 and 2.

The modified ADAMS model was used to evaluate:

- the overall aircraft behavior as compared against that observed from physical and flight recorder evidence for the accident airplane
- loads in the landing gear elements
- interface loads between the gear and the wing fitting, and between the side brace fitting and the trap panel
- loads in the rear spar shear web (inboard of wing station 264)

The behavior of this shear web-failed model looked reasonable insofar as it represented the beginning of the failure sequence. This model appeared to overestimate the residual strength and stiffness of the accident aircraft however, since it did not idealize subsequent, progressive wing box element failures. Logistics issues (complexity, computer time, etc.) prevented creating a model

[68] The recorded lateral acceleration at touchdown on the Martinair DC-10 at Faro was very similar, roughly 0.4 g, to the recorded lateral acceleration from the accident MD-11 aircraft.

which would allow for sequenced failures so an "extreme case" single-failure idealization was used. In this idealization the entire wing cross-section was analytically failed just inboard of the landing gear support (264) bulkhead. See Figure 3 in Appendix 5.11. Please note that the models of the left and center main landing gears and the nose landing gear are simplified such that they appear to penetrate the ground plane in Figures 2 and 3 of Appendix 5.11

Results of the modified ADAMS simulations showed that the internal loads in the rear spar exceeded those required to fail the spar web and caps. The overall aircraft behavior also demonstrated trends that matched with the physical evidence and flight recorder data. Notable among these are:

- bending loads applied to the RMLG forward axle
- the "track" of the RMLG tires (a sudden outboard motion)
- contact of the right engine nacelle with the runway
- relative movement of the wing to the fuselage side-of-body that would cause the inboard flap to depart the aircraft
- relative movement of the wing to the fuselage side-of-body that would impart high loads on (and cause failure of) the side-brace-fitting-to-trap-panel joint

Physical examination of the RMLG forward axle revealed that it was slightly bent. The forward axle loads generated by the ADAMS idealization match this finding. (The loads were above the estimated yield load and were below the estimated failure load).

The ADAMS analysis shows a very good match with the RMLG tire "tracks" observed and documented in the factual reports. Failure of the rear spar results in a nose-down twist ("racking") of the wing outboard of wing station 264. This twist produces upward relative motion of the landing gear support fitting and effectively causes the gear assembly to pivot about the trap panel attach point. This motion "swings" the landing gear rolling assembly outboard and results in an abrupt lateral scrubbing of the tires. See Illustrations 6 and 7.

The nose-down wing twist noted above also contributes to the right engine nacelle contacting the runway. In the rear-spar-web-failed idealization the nacelle makes contact only momentarily. This conflicts with the documented runway scar data where the nacelle scrape is long and continuous. The explanation for the difference is that in this idealization only the rear spar web is failed. In contrast, the accident airplane undoubtedly saw a rapid progression in the collapse of wing box elements following failure of the rear spar web. This explanation is further supported by the entire-wing-cross-section-failed ADAMS analysis, which shows that the right engine nacelle, once it contacts the runway, stays in contact.

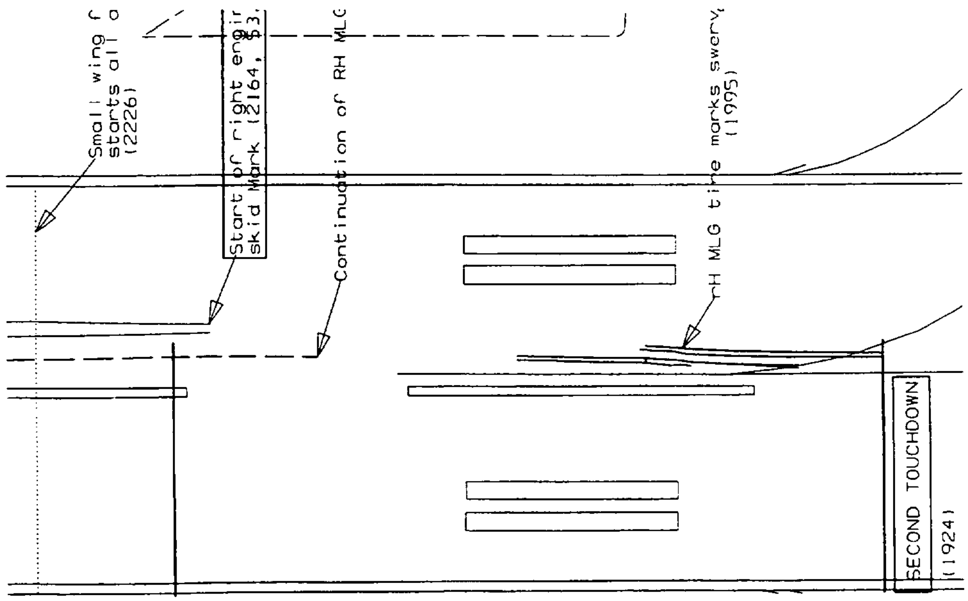


Illustration 6
RMLG Tire "Swerve" Marks From Runway Measurement

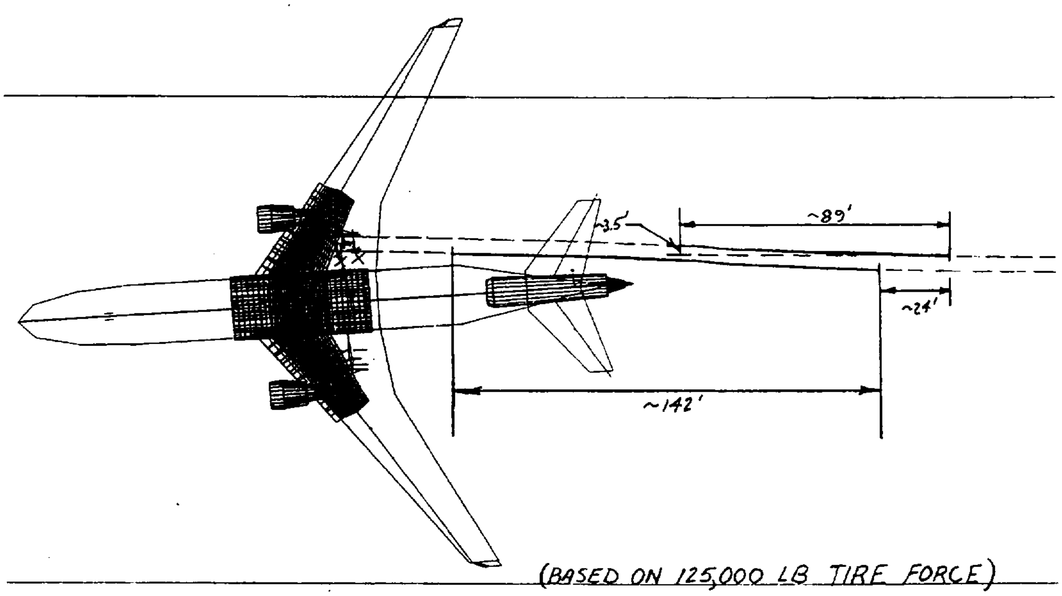


Illustration 7
RMLG Outboard Motion from ADAMS Analysis

Evidence from the crash site points to the fact that the right-hand inboard flap departed the aircraft early in the accident sequence. The flap was found at the beginning of the debris field and showed no evidence of fire or heat damage.

Understanding how the early departure of the inboard flap is connected to the wing failure sequence requires an understanding of how the inboard flap is supported. The inboard flap is supported at two locations. The outboard support is a hinge arrangement and hangs off the wing rear spar just outboard of the landing gear support fitting. The inboard support is a track/roller arrangement with the rollers mounted to the side of the fuselage. Examination of the inboard support track revealed a failure of the "lip" where it is captured by the side roller, at a location consistent with the flap in the fully extended position (see Figure 142 of MDC 98K1023). This failure suggests that the flap track was pulled or pried in an outboard direction. Although the inboard flap was not modeled in the ADAMS idealization, the analysis shows large relative motion between the above noted support points, and it is easy to visualize from this motion how the flap would have been pulled off the inboard rollers. This would then have freed the flap at the inboard end causing it to twist off its outboard support. Examination of the flap and it its support structure shows failures consistent with this theory.

In a similar fashion the large relative motion between the landing gear support fitting (at the 264 bulkhead) and the fuselage side-of-body imparted large loads on the side-brace-fitting-to-trap-panel joint. Examination of this joint revealed evidence of the existence of a "prying moment" about the aircraft roll axis. Upward motion of the landing gear support fitting (as observed in the ADAMS analysis) explains the origin of this prying force. The outboard end of the fixed side brace is attached to the wing fitting and moves upward with it. If the upward motion exceeds roughly 14 inches, the inboard clevis of the fixed side brace contacts the side brace fitting and begins to pry the joint in a manner consistent with the metallurgical evidence.

Also evident from the examination of the side-brace-fitting-to-trap-panel joint was damage consistent with the application of a "rocking moment" about the aircraft pitch axis. Wing deformation of the type observed in the ADAMS analysis also explains this damage. The upward motion of the landing gear support fitting is a manifestation of the outboard wing twisting about an axis forward of the front spar. The angular change (twist) effectively "tilts" the landing gear strut as it moves upward. This "tilt" is transmitted to the side brace fitting by the combination of the fixed and folding side braces thus the "rocking" motion and the associated load.

In summary, the ADAMS analysis of the accident identifies loads in the right-hand inboard wing rear spar web in excess of those required to fail the web. Two ADAMS idealizations were created that model failure of the wing, presuming the failure initiates in the inboard rear spar web. These idealizations, which represent two extremes in terms of the damage progression in the inboard wing, produce structural deformation, loads and overall aircraft behavior that show good correlation with accident evidence.

[NOTE: Selected animations of the ADAMS analyses were provided to the NTSB and parties to the investigation prior to this Submittal. Included were animations of the model without structural fuses ("unfused"), animations of the rear-spar-web-failed model ("fused"), and animations of the entire-wing-cross-section-failed model ("3pfused").]

2.7 BOEING FOLLOW-ON ACTIONS

Boeing has begun an evaluation into the net safety benefit of installing a fuse for vertical overload in the DC-10 and MD-11 main landing gear. The evaluation requires extensive analysis and research (including a thorough review of Boeing and other manufacturer's transport aircraft service history), and could take a year or more to complete. Boeing is also participating in an ongoing Federal Aviation Administration (FAA) evaluation of the adequacy of the landing gear sink rate design criteria.

Although the handling qualities of the MD-11 during landing were not a subject of this investigation, it should be noted that Boeing has nearly completed a program to revise the software of the Flight Control Computer (FCC). The FCC update project began before this FedEx accident, and was initially intended, as part of a continuous product improvement program, as an additional method to deter tailstrikes. The update has since grown into a means of making the MD-11 pilot handling forces during landing more closely match those of the MD-10 and DC-10. Boeing recommends that all MD-11 operators update their FCC software when the change becomes available later this year.

The NTSB has asked Boeing to comment on possible recommended changes to the FARs, such as an increase in the landing gear sink rate requirements, or a mandate to fuse the landing gear for high vertical loads. Since the evaluation described above has not been completed, Boeing has no recommendations for FAR changes at this time.

However, there are some things to consider when evaluating a possible increase in energy absorption capability from a high vertical energy landing condition, such as: 1) additional landing gear energy absorption capability would have a cascading effect in that the total aircraft structure would have to be strengthened to absorb the additional energy; and 2) the question could still arise as to whether the new design requirements would adequately fulfill the intent of the changes, as an increase in design energy absorption limits does not in itself prevent aircraft from suffering severe impacts well outside of those new limits.

Alternatively, if the FARs were changed to mandate a main landing gear fuse for vertical overloads, there remains the issue of how significant a safety improvement is truly effected. Creating a reliable vertical fuse can only be accomplished by adding weight and complexity. Setting the fusing threshold at a load level consistent with aircraft design requirements (not well above them) would be necessary to keep the added weight within reasonable boundaries. As a consequence, high vertical sink rate landings that would not have damaged some of today's aircraft (that were designed using a "robust gear" philosophy) could fuse the gear, cause significant damage and/or result in diminished control.

It must also be recognized that an aircraft's remaining energy of vertical descent must still be absorbed after one-or-more landing gear have absorbed their share and fused. Additionally, for cases where the aircraft's attitude and speed are such that its weight is only partially supported by aerodynamic lift, the aircraft would be accelerated into the ground over the distance the aircraft "falls" after the gear is/are removed. (This "falling" phenomenon can add substantially to the effective energy of vertical descent that must be absorbed after the gear is/are gone).

For symmetric landings where both main landing gear fuse, the (remaining) energy of vertical descent would largely be absorbed by crushing the lower fuselage. (This assumes that wing mounted engines/nacelles are also fused for vertical loads, and that the amount of energy absorbed by fusing them is relatively small, generally a good assumption for today's aircraft). For very high sink rate landings this is a desirable situation, preferable to tearing open one or both wing tanks and causing a fire. An even more desirable situation of course, is that there is no damage (or only minor damage) to the aircraft, a design goal that can be met in a probabilistic sense, if the statistically appropriate sink rate design goal is chosen for the "robust" design approach.

Additional considerations arise for unsymmetric (rolled attitude) landings. For extreme roll angles the landing gear design criteria and philosophy do not come into play. Striking the wingtip may fail the wing directly or may cause the aircraft to "cartwheel". For lesser roll angles the single gear on the "wing low" side may fail (or fuse if it is so designed) if the combination of sink rate and roll rate (and amount of wing lift) impart loads that exceed the design thresholds. For "fused" aircraft the (remaining) energy of vertical descent would then be absorbed by flexing the low-side wing, or by some combination of exercising the high-side landing gear, and flexing the low-side wing. (Note that, once again, we are discounting the energy absorbed by fusing the low-side wing engine/nacelle as small). For some combinations of sink and roll rates the low-side gear may fuse (followed by the wing engine/nacelle) and the aircraft may "settle in" on the remaining gear and the low-side wing without compromising fuel tank integrity. For higher sink and roll rates (or lower amounts of wing lift) the low-side wing may fail nonetheless, as a result of exceeding its flexure (bending) limits.

The NTSB has asked Boeing to comment on the initial failure sequence that would likely have occurred during the Newark accident if a vertical fuse had been incorporated in the MD-11 main-landing-gear/wing design. Any answer to this question would be speculative due to the many assumptions that would have to be made in that evaluation.[69] Boeing does intend to include, however, a scenario similar to the Newark accident (among many others) in its study of the potential safety benefits of crashworthiness-improving design enhancements that are proposed during the upcoming evaluation.

[69] Such as, but not limited to: 1) the amount of energy absorbed by the RMLG before fusing; 2) where the RMLG would go after it fused and what kind of damage it might inflict to the aircraft after fusing; 3) lift generated by the right wing as wing leading and trailing edge lift devices come into contact with the runway; 4) what happens to the engine/pylon combination after the pylon fuses; and 5) flight control inputs from the pilot after the second touchdown impact.

3 CONCLUSIONS

3.1 FINDINGS

1. Aside from the inoperative No. 1 engine thrust reverser and left landing light, the aircraft and its systems were functioning normally at the time of the accident.
2. All observed primary structural failures of the aircraft were the result of ductile overload.
3. The condition and operability of the active and inactive passenger exit doors immediately after the aircraft came to rest, other than the R1 door, is not known.
4. Weather, communications, and air traffic control were not contributing factors.
5. The aircraft's approach to Newark runway 22R was stabilized and on glide path and localizer until just prior to the first touchdown.
6. The accident landing flare was not consistent with Boeing Long Beach Division (BLBD)-recommended and published landing procedures and techniques. A go-around, initiated when the pilot believed that large control deflections and throttle inputs had become necessary just before the first touchdown, would have been consistent with BLBD-recommended and published procedure.
7. The control inputs recorded just before the first touchdown and between the first touchdown and second touchdown impact were not consistent with FedEx's "High Sink Rate and Bounce Recovery Technique" recommendations.
8. The large pilot-commanded AND elevator control inputs prior to second touchdown impact, in combination with RWD aileron inputs and power reduction, resulted in a high RMLG sink rate and loads in excess of established design loads which fully compressed (bottomed) the RMLG strut.
9. The large pilot-commanded AND elevator control inputs prior to second touchdown impact also resulted in a nose-down pitch rate that reduced the aircraft's recorded vertical acceleration from approximately 1.0 g to approximately 0.5 g at second touchdown impact.
10. The decrease in recorded vertical acceleration at the second touchdown impact introduced loads into the RMLG that are normally obviated by 1.0 g wing lift, and that were additive to the loads on the RMLG resulting from the combined sink and roll rates.
11. The bottomed RMLG strut introduced large loads into the landing gear and wing structure that were far in excess of established design loads.
12. The energy introduced into the RMLG at second touchdown impact was greater than FAR 25.723-defined design ultimate conditions by a factor of 3.
13. The aircraft was certified to, and met or exceeded, all applicable FAA requirements.

4 SAFETY RECOMMENDATIONS

Now that the extensive analysis into identifying the sequence of initial structural failures occurring during the Newark accident is complete, and with consideration given to the Faro DC-10 and JFK L-1011 accidents, Boeing has begun an evaluation into the safety benefits of installing a vertical fuse on the DC-10 and MD-11 landing gear. The evaluation will require further extensive analysis and research; the results will be provided to the NTSB upon completion. Boeing also intends to continue with its participation in the FAA's review of the landing gear sink rate design requirements, and with the product improvement development of updated FCC software.

In addition, Boeing suggests the following Safety Recommendations specific to this accident:

1. *Operators should stress to their flight crews the importance of executing a go-around any time below approximately 500 ft. above ground level (AGL) that a stable approach becomes destabilized. As a general "rule of thumb," if large power and/or control deflections are required to maintain the desired flight path and/or alignment with the runway, then a go-around is warranted.*
2. *Manufacturers should revise their Maintenance Manual hard landing defining and inspection criteria to include information on the effects of reduced lift and adverse aircraft attitude on loads into the landing gear. Data developed during this investigation show that the absolute recorded vertical acceleration value during landing should not be the only criteria for determining if a hard landing has taken place. The recorded vertical acceleration at the beginning of the touchdown can also be very important. Specifically, if the recorded vertical acceleration at the beginning of the landing is less than 1.0 g, then aircraft weight that is normally accommodated by 1.0 g wing lift is instead transmitted into the landing gear on top of the loads required to decelerate the airplane vertically from the aircraft's sink rate. The effects of non-routine aircraft pitch and roll attitudes on energy introduced into a singular landing gear should also be a part of a hard landing evaluation. For example, nose landing gear-first firm landings, or firm landings in a significant left or right wing down roll attitude or with a rapid roll rate may warrant a hard landing inspection if most of the landing energy absorption is accomplished by one landing gear. Boeing is in the process of revising the MD-11 Maintenance Manual (MM) to incorporate this type of information; once the MD-11 MM is revised, it will be used as the guide for revising the other Boeing MMs.*
3. *Operators should be made aware of the issues discussed in Recommendation 2 above so that they can more thoroughly evaluate the severity of a hard landing from available data. Boeing is preparing an operator advisory on this subject.*

BOEING

Boeing suggests the following Safety Recommendations generic to landing safety issues:

1. *Tailstrikes, hard landings, hard nose landing gear touchdowns, and other landing difficulties seem to occur on a periodic or cyclical basis. Data shows that increased education and awareness has a strong positive impact on the rate of these incidents and accidents. Operators that haven't done so already should therefore consider developing periodic awareness and training to address landing issues and then ensure that all crew members receive this training.*
2. *Operator management and Air Traffic Control personnel who are not already aware of the safety benefits associated with proactive go-arounds need to be aware of, and endorse, the use of the go-around as an accident avoidance maneuver.*

5 Appendices

5.1 NTSB Cockpit Voice Recorder Transcript

NATIONAL TRANSPORTATION SAFETY BOARD
Engineering & Computer Services Division
Washington, D.C. 20594

SPECIALIST'S FACTUAL REPORT OF INVESTIGATION

Cockpit Voice Recorder

DCA97MA055

by

Vincent M. Giuliana
Electronics Engineer/CVR

Warning

The reader of this report is cautioned that the transcription of a CVR tape is not a precise science but is the best product possible from an NTSB group investigative effort. The transcript, or parts thereof, if taken out of context, could be misleading. The attached CVR transcript should be viewed as an accident investigation tool to be used in conjunction with other evidence gathered during the investigation. Conclusions or interpretations should not be made using the transcript as the sole source of information.

NATIONAL TRANSPORTATION SAFETY BOARD
Office of Research and Engineering
Washington, D.C. 20594

October 22, 1997

Cockpit Voice Recorder

Group Chairman's Factual Report
by Vincent M. Giuliana

A. ACCIDENT

Location:	Newark International Airport Newark, NJ
Date:	July 31, 1997
Time:	0132 Eastern Daylight Time (EDT)
Aircraft:	Federal Express Flight 14 MD-11, N611FE
NTSB Number:	DCA97MA055

B. GROUP

Chairman:	Vincent M. Giuliana Electronics Engineer/CVR National Transportation Safety Board
Member:	David Kirchgessner Federal Aviation Administration
Member:	Larry Wilkinson FedEx Pilots Association
Member:	Thomas R. Nordberg Flight Standards MD-11 Federal Express Corporation
Member:	Captain T.J. Melody Chief Pilot Boeing (McDonnell Douglas Corporation)

C. SUMMARY

This transcript was derived from a Fairchild Cockpit Voice Recorder (CVR) (Model A100A, S/N 25685) removed from the accident aircraft and delivered to the audio laboratory of the National Transportation Safety Board.

The playback time of the recording was approximately thirty minutes and twenty-five seconds (30:25), all of which was transcribed. All times incorporated into the transcript are in eastern daylight time, correlated with a copy of the New York TRACON audio tape provided by the Federal Aviation Administration.

D. DETAILS OF INVESTIGATION

Three channels of the CVR contained audio information from the cockpit area microphone (CAM), the captain's position and the first officer's position. The fourth channel had no useful information.

The entire external surface of the CVR was scorched and coated with soot but showed only limited impact (structural) damage. The internal crash case was also scorched and heavily discolored but showed no impact damage. Although portions of the thermal jacket's outer casing was melted and the inner material dry and crumbly, any apparent heat damage sustained by the tape was limited to several center-spooled layers that were notably brittle and crinkled.

Consistent with its apparent heat damage, fluctuations in the tape's audio amplitude were evident during the first five minutes of playback. Subsequently, however, the quality of the recording was good', enhanced by the eventual use of crewmember "hot" microphones at time 0106:08 of the transcript.

The captain was the only crewmember to accept the invitation to audition the CVR tape and review the transcript. He had no comments or suggested corrections to the transcript.

The transcript begins as Fedex flight fourteen was in contact with the Boston Air Route Traffic Control Center. According to a radio call at 0102:11, the aircraft was above flight level one eight zero.

Vincent M. Giuliana
Electronic Engineer/CVR

Transcript of a Fairchild cockpit voice recorder (Model A100A, S/N 25685) installed on a MD-11, N611FE, which was involved in an accident at the Newark International Airport, NJ on July 31, 1997.

LEGEND

CAM	Cockpit area microphone
INT	Aircraft intercom system
HOT	Crewmember "hot" microphone
RDO	Radio transmission from accident aircraft
-1	Voice (or position) identified as Captain
-2	Voice (or position) identified as First Officer
-3	Voice (or position) identified as Jump Seat Rider
-?	Unidentifiable voice
ZBW	Boston Air Route Traffic Control Center (ARTCC)
RAMP	FedEx Newark Operations
MAINT	FedEx Newark Maintenance
NYAPP	New York Terminal Radar Approach Control (TRACON)
ATIS	Newark Automatic Terminal Information Service (ATIS)
EWR	Newark Air Traffic Control Tower, Local Control

Note: Unless otherwise noted, only those radio transmissions to and from the accident aircraft were transcribed.

LEGEND (continued)

*	Unintelligible word
#	Expletive deleted
...	Pause
( )	Questionable text
[ ]	Editorial insertion
-	Break in continuity

[i] CVR Quality Rating Scale

The levels of recording quality are characterized by the following traits of the cockpit voice recorder information:

Excellent Quality Virtually all of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate only one or two words that were not intelligible. Any loss in the transcript is usually attributed to simultaneous cockpit/radio transmissions that obscure each other.

Good Quality Most of the crew conversations could be accurately and easily understood. The transcript that was developed may indicate several words or phrases that were not intelligible. Any loss in the transcript can be attributed to minor technical deficiencies or momentary dropouts in the recording system or to a large number of simultaneous cockpit/radio transmissions that obscure each other.

Fair Quality The majority of the crew conversations were intelligible. The transcript that was developed may indicate passages where conversations were unintelligible or fragmented. This type of recording is usually caused by cockpit noise that obscures portions of the voice signals or by a minor electrical or mechanical failure of the CVR system that distorts or obscures the audio information.

Poor Quality Extraordinary means had to be used to make some of the crew conversations intelligible. The transcript that was developed may indicate fragmented phrases and conversations and may indicate extensive passages where conversations were missing or unintelligible. This type of recording is usually caused by a combination of a high cockpit noise level with a low voice signal (poor signal-to-noise ratio) or by a mechanical or electrical failure of the CVR system that severely distorts or obscures the audio information.

Unusable Crew conversations may be discerned, but neither ordinary nor extraordinary means made it possible to develop a meaningful transcript of the conversations. This type of recording is usually caused by an almost total mechanical or electrical failure of the CVR system.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0102:03 Beginning of Recording			
0102:03 Beginning of Transcript			
		0102:03 RDO-2	that's affirm SHAFF three after Hancock FedEx fourteen heavy.
		0102:06 ZBW	roger.
		0102:11 ZBW	okay FedEx fourteen, descend and maintain flight level one eight zero.
0102:15 CAM-1	that's affirm.		
		0102:17 RDO-2	down to flight level one eight zero, FedEx fourteen heavy.
0102:22 CAM-1	ah ..... remind me to - we still want two and three for reverse.		
0102:27 CAM-2	yeah, okay.		
0102:29 CAM-1	* * * ... you might ask him if wants that at our discretion * * *.		
0102:34 CAM-?	***.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0102:35 RDO-2	and Boston center FedEx fourteen heavy, you want us out of ah three three zero at this time?
		0102:47 ZBW	ah ... yeah .. you can start a gradual descent.
		0102:52 RDO-2	and fourteen heavy roger.
0103:00 CAM-2	(isn't) this the APLC when it plugs out those distances?		
0103:03 CAM-1	yup.		
0103:04 CAM-2	that includes the ah ... runway you have before touchdown, right?		
0103:10 CAM-1	(gimme) that again.		
0103:11 CAM-2	I said that includes the ah .. that includes the runway that's used up prior to touchdown, right?		
0103:21 CAM-1	for which? beyond (beyond) the glide slope?		
0103:23 CAM-2	yeah.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0103:23 CAM-1	yeah, that's showing you how much you got remaining. if you fly the glide slope and you're right on it you've got sixty-eight. twenty-two ah right okay which is the one we're looking at, right?		
0103:33 CAM-2	yeah, twenty-two right's got (so beyond is sixty-eight sixty).		
0103:35 CAM-1	sixty-eight sixty.		
0103:37 CAM-2	so if we go medium brakes we're gonna have eight hundred. so does that mean if we go medium brakes landing on this runway we'll have eight hundred and .. eight hundred feet (in front of us) when we come to a stop?		
0103:47 CAM-1	yeah, *.		
0103:48 CAM-2	you don't want to go maximum? you wanna go max?		
0103:50 CAM-1	well we can .. we'll see how it goes .. I don't know. we we can probably as a matter of fact, we can we can start max if it makes you feel better and then we'll ah come off * * come on off regardless.		
0103:57 CAM-2	yeah, *.		

INTRA-COCKPIT COMMUNICATION | **AIR-GROUND COMMUNICATION**

TIME and SOURCE	CONTENT	TIME and SOURCE	CONTENT
0103:59 CAM-1	*, we got .. we got a lot of stuff going against us here so we'll .. we'll start with max * * * *.		
0104:03 CAM-2	I mean .. I mean if we don't have the reverser so -		
0104:04 CAM-1	yeah that -		
0104:05 CAM-2	* * * *.		
0104:06 CAM-1	that sounds good to me .. I'd rather play it that way. that was my original plan then I started thinking well we gotta a little plan here. most likely we're gonna go .. after we land we'll most likely probably plan to go to the end anyway to turn off at Victor .. that's what I'd like to do .. cause we come down here and make a left turn and then ah .. I think they park us over here so we"ll come in this Pappa Charlie and your deal on that is to ah -		
0104:32 CAM-2	(not) Pappa Charlie.		
0104:34 CAM-1	(you see) Pappa - sometimes sometimes you might go in Pappa Bravo .. depends where they park us.		
0104:37 CAM-2	yeah.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0104:38 CAM-1	but ah I been .. last few number of times I've come in we park over in this section right here .. but you're supposed to stay on ah ground until you get up to Pappa -		
0104:48 CAM-2	until you turn in basically.		
0104:49 CAM-1	yeah Pappa Charlie but when you get over here you're supposed to contact them some point in time to make sure the gate's still the same.		
0104:54 CAM-2	yeah.		
0104:56 CAM-1	anyways, if you're ready, we'll go dark.		
0104:58 CAM-2	yup, I'm all set.		
0105:07 CAM-?	* *.		
0105:13 CAM-2	why would this be saying IRS ONLY navigation * *?		
0105:17 CAM-1	it's just not picking up ah whatever .. I don't know .. don't ask me why .. it should be picking up plenty of VORs out here.		
0105:28 CAM-2	* * * *.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0105:33 CAM	[sound of several loud clicks]		
0105:44 CAM-1	I believe we should be getting an in-range deal from these guys telling us what our gate assignment is but ah in the event we don't get one say-		
0105:52 CAM-2	why don't I call them right now.		
0105:53 CAM-1	okay, you can give them a call.		
0106:06 CAM-2	okay, I'm going up on two.		
0106:08 HOT-1	okay, I've got one.		
		0106:20 RDO-2	Newark ramp FedEx fourteen heavy.
		0106:25 RAMP	fourteen heavy parking gate thirty-one, negative ground power.
		0106:32 RDO-2	roger that thirty-one I'll start the APU. we'll probably be in around forty-five.
		0106:35 ZBW	FedEx .. FedEx fourteen Boston center one three four point three.

INTRA-COCKPIT COMMUNICATION

TIME and SOURCE	CONTENT
0106:58 HOT-2	gate thirty-one.
0107:06 HOT-1	three one?
0107:06 HOT-2	yeah.
0107:10 HOT-1	it's over in that -
0107:11 HOT-2	yeah, right where you said we'd be.

AIR-GROUND COMMUNICATION

TIME and SOURCE	CONTENT
0106:37 RAMP	copy that.
0106:39 RDO-1	thirty-four point three, roger.
0106:41 RDO-2	and it might be a little sooner .. we might be in around thirty-five to forty-five for FedEx fourteen heavy.
0106:45 RAMP	fourteen heavy roger.
0106:50 RDO-1	ah good morning Boston .. FedEx fourteen is with you out of twenty-one five for one eight zero.
0106:56 ZBW	fourteen roger.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0107:16 HOT-2	we're way down at the end there ... there right where you said.		
0107:17 HOT-1	got it .. so we'll be going in that ah Pappa Charlie and ah somewhere along the line when we get down there you can advise the ground .. the ground control that that's where we want to go in.		
0107:29 HOT-2	okay.		
0107:29 HOT-1	cause a lot of times they'll be expecting us to come in that other direction there.		
0107:42 HOT-1	[sound of human whistling]		
		0107:45 ZBW	FedEx fourteen verify you're going to Newark tonight.
0107:48 CAM	[sound of tone and verbalized "altitude" from the CAWS]		
0107:49 HOT-1	that's affirmative.		
		0107:50 RDO-2	FedEx fourteen that's affirmative we're going to Newark.
0107:56 HOT-2	there's coming up on eighteen thousand.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0107:56 HOT-1	boy that cuts it close, don't it.		
0108:06 HOT-2	I started to reach for the hand mic.		
0108:34 HOT-1	[sound of human whistling]		
0108:39 HOT-1	you might ask him if he's gonna expect us to ah cross the ah SPARTA twenty-five degree at eight thousand feet ... or twenty-five miles at eight thousand feet.		
0108:53 HOT-2	is this .. who is this Boston still?		
0108:55 HOT-1	it's Boston, yeah.		
		0108:59 RDO-2	ah Boston FedEx fourteen heavy are you expecting us to cross the SPARTA at twenty-five at ah eight thousand?
		0109:05 ZBW	(probably) at seven yeah .. can't do anything for another ten miles .. we do it every day .. don't worry .. I'll take care of you.
		0109:09 RDO-2	roger.
0109:12 HOT-1	I think I'm gonna cut this radar off .. I don't think we need it.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0109:15 RDO-2	yeah.
0109:16 HOT-1	get all the glitter out of there ... anyways ah we're at eighteen .. we can do an in-range.		
0109:24 HOT-2	roger that.		
0109:47 HOT-2	(I say) for altimeter there?		
0109:49 HOT-1	three zero two four huh. yeah I'm just gonna hold on the altimeter until we go below eighteen.		
0109:54 HOT-2	thirty twenty-four, okay.		
0110:14 HOT-1	thirty miles.		
		0110:15 ZBW	FedEx fourteen cross twenty-five north of SPARTA at seven thousand .. altimeter three zero two seven.
		0110:21 RDO-2	roger twenty-five north of SPARTA at seven thousand three zero two seven FedEx fourteen heavy.

INTRA-COCKPIT COMMUNICATION | **AIR-GROUND COMMUNICATION**

TIME and SOURCE	CONTENT	TIME and SOURCE	CONTENT
0110:29 HOT-1	okay seven is the number .. I'm gonna put ten in here for just a second so I can get it to slow .. without shooting through there ... and three zero two seven.		
0110:50 HOT-2	so won't it slow down automatically?		
0110:53 HOT-1	well I'm .. I level changed it just to get it to go down quicker.		
0110:56 HOT-2	oh, okay.		
0110:57 HOT-1	and we're behind as it is anyways.		
0111:01 HOT-2	so do you have to keep that ten in until we get to ten basically before you put seven in?		
0111:04 HOT-1	well, it's the safe way to do it.		
0111:05 HOT-2	yeah, okay.		
0111:06 HOT-1	it's just not a .. it's a technique more than anything else but ah -		
0111:11 HOT-2	yeah, I'm just starting to learn. okay yeah it's ah three zero two seven on the altimeters and in-range check is complete.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0111:12 CAM	[sound of chime similar to that of ACARS message]		
0111:18 HOT-2	gate thirty-one north is what they're saying. negative ground power.		
0111:36 HOT-1	so like we've got thirty-one miles to make that and we've got ah what ah four, three, seven, twenty-one we're looking good.		
0111:43 HOT-2	seven'll be twenty-one, yeah we're fine.		
0111:50 HOT-1	now what I could do .. when this comes back .. go back to PROF .. then I put seven in here and now it will do it automatically.		
0111:59 HOT-2	and you probably pop the -		
0112:00 HOT-1	it's just when you come out of ah -		
0112:02 HOT-2	then you pop the drag out then too huh?		
0112:05 HOT-1	when you come out of that deal there it's ah .. out of PROF you're on your own. if you put something lower than ten thousand -		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	CONTENT	TIME and SOURCE	CONTENT
0112:12 HOT-2	yeah.		
0112:13 HOT-1	in there and you just level change it, it'll shoot right on by.		
0112:15 HOT-2	oh it will? okay		
0112:16 HOT-1	yeah.		
0112:27 HOT-2	well this should be at seven thousand not eight thousand here.		
0112:30 HOT-1	well below seven or ah -		
0112:32 HOT-2	well I mean that's what he wanted us at seven right so I can come over here and go like this.		
0112:34 HOT-1	okay yeah you can put it ah you can put it at seven if you'd like.		
0112:41 HOT-1	you need a slash in there though, you got it?		
0112:42 HOT-2	yeah I was gonna go -		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0112:47 HOT-1	I'm just gonna help this out a little bit. let's see .. we got ah seven three -		
0112:57 HOT-2	it's saying not allowed.		
0113:00 HOT-1	well .. oh you're on the DIRECT TO page.		
0113:02 HOT-2	oh okay.		
0113:02 HOT-1	you need to go back to FLIGHT PLAN.		
0113:08 HOT-2	first time I did that.		
0113:13 HOT-1	just ignore the speed limit exceeded .. it's not a problem.		
0113:49 HOT-1	gotta clear that BUTTON PUSH IGNORED outta there ... there you go.		
0113:57 HOT-1	that's okay .. when we're around the bend here I'll just level change it and it'll .. it'll do its thing there.		
0114:00 HOT-2	there it goes.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0114:01 HOT-1	it'll make it quicker.		
0114:22 HOT-1	you might wanna tell those girls in the back that ah we're gonna have a pretty abrupt stop because of those brakes and the thrust reversers and all that stuff so.		
0114:28 HOT-2	okay.		
0114:32 HOT-1	which if you actually you can use your microphone and push forward on your push-to-talk switch and that'll just use the interphone back there.		
0114:36 HOT-2	okay.		
		0114:43 RDO-2	yeah we should be on the ground here in about .. about another fifteen twenty minutes .. we're gonna have a pretty quick stop here because we're landing on a short runway just to give you guys a heads up in the back there.
		0114:54 ZBW	I appreciate it.
0114:56 HOT-1	did you pull back or push forward?		
0114:59 HOT-2	I pushed it forward.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0115:01 HOT-1	ah well it should be. test. it should just go to the back if you push forward on it.		
0115:08 CAM	[sound of tone and verbalized "altitude" from the CAWS]		
0115:08 HOT-1	two one.		
0115:11 HOT-2	just went like that.		
0115:13 HOT-1	there you go .. that'll work.		
0115:17 HOT-2	try [sound of laughter]		
0115:20 HOT-1	oh well.		
0115:20 INT	to give you guys a heads up we're gonna be landing pretty ah pretty quick here .. we've got about another fifteen minutes to go to get on the ground .. we got a short runway so .. so let you know that the aircraft is going to be stopping pretty quick.		
0115:36 HOT-2	[sound of laughter]		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0115:39 HOT-1	I'm sure you're the only guy in this airline that's ever done that before.		
0115:43 CAM-3	I've never done that.		
0115:44 HOT-1	nah, me neither.		
0115:44 CAM-3	[sound of laughter]		
0115:46 HOT-2	I don't know what in the world happened .. I mean I was pushing on that thing forward.		
0115:49 HOT-1	you can turn on those lights if you would.		
0115:51 HOT-2	yeah sure.		
0115:52 HOT-1	ah landing lights.		
0115:53 CAM	[sound of several clicks]		
0115:56 HOT-1	and in-range is complete, correct?		
0115:57 HOT-2	yes.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0115:59 HOT-1	yeah, we made that with plenty of room to spare.		
0116:16 HOT-1	looks like we got one burned out.		
0116:28 HOT-1	just having all kinds of fun here.		
0116:29 HOT-2	left side's out, huh?		
0116:31 HOT-1	well let's see.		
0116:32 HOT-2	is the left side out?		
0116:33 HOT-1	think so.		
0116:35 HOT-1	yeah, just the right's working.		
0116:39 HOT-1	well I guess we got another thing we'll write up.		
0116:45 HOT-2	should I punch that over to maintenance real quick?		
0116:48 HOT-1	say again.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0116:49 HOT-2	want to ACARS 'em real quick or just let them know?		
0116:52 HOT-2	I'll call Newark real quick.		
0116:53 HOT-1	no, I don't think it's a big issue. they'll defer it if they have to but -		
		0117:07 RDO-2	Newark maintenance FedEx fourteen.
		0117:15 MAINT	fourteen maintenance.
		0117:17 RDO-2	yeah maintenance fourteen .. just giving you a heads-up .. our left landing lig ' is inoperative.
		0117:25 MAINT	okay fourteen we'll see you at the gate.
		0117:27 RDO-2	bye.
0117:29 HOT-1	like these guys care. [sound of laughter] Newark .. these guys you'll find are some of the worst mechanics we've got in the system. man these guys don't do anything ...... they got a note in the little orange pages down here -		
0117:44 HOT-2	ah huh.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0117:45 HOT-1	that when you .. for the parking spot we're going to .. that if there's any containers on the right-hand side there by the blast fence .. you'll see this blast fence when we get up there -		
0117:53 HOT-2	yeah.		
0117:54 HOT-1	that ah uhm that you're supposed to shut down and get towed in. ah so in theory, they're supposed to always clear those out .. and you .. there'll be a hundred of them over there .. if there's any .. if there's .. I mean it'll they'll just be all over the place .. it just depends on how ah .. how tight we are here but at least we'll have the blast fence.		
0118:15 HOT-1	yeah, we're going to thirty-one you said?		
0118:16 HOT-2	yes.		
0118:17 HOT-1	yeah.		
0118:18 HOT-2	it's right down at the end there.		
0118:19 HOT-1	they can't go too far but .. I've actually just stopped it right there and told them to tow us in before.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0119:02 HOT-2	luckily the controller probably thinks that I was a ah some passenger airline flight engineer calling up the flight attendants or something.		
0119:08 HOT-1	what's that?		
0119:09 HOT-2	I said hopefully the center will probably thinks that I was a ah some passenger airline calling the flight att -		
0119:13 HOT-1	yeah, he wouldn't figure that it's us ah -		
0119:15 HOT-2	not FedEx.		
0119:16 HOT-1	freight dogs.		
0119:21 HOT-2	[sound of laughter]		
0119:24 HOT-1	ah it barely matters.		
0119:37 HOT-1	[sound of human whistling]		
0119:40 HOT-2	I heard a captain once give a whole .. briefing on weather .. their route of flight and everything to the passengers over the radio one time. it was pretty funny.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0119:49 HOT-1	[sound of laughter]		
0119:50 HOT-2	I was flying with Delta.		
0119:51 HOT-1	probably talking for twenty minutes man.		
0119:52 HOT-2	yeah ... I bet every air .. every airline in the system was calling him up and saying yeah that sounded real good yeah you know.		
0120:00 HOT-1	[sound of laughter]		
0120:00 HOT-2	really giving him .. really giving him #.		
0120:02 HOT-1	ah.		
0120:03 HOT-2	and all these other airlines, United .. and all that stuff.		
0120:22 HOT-1	any time boys.		
		0120:30 RDO-1	folks don't seem to be overly busy this evening.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0120:36 HOT-1	yeah and they won't talk to us .. ah see .. we probably should be talking to New York or something.		
		0120:46 ZBW	who's that calling?
		0120:48 RDO-1	that was FedEx fourteen .. I was just saying that ah it seems awfully quiet out here, we weren't sure we still had you anymore.
		0120:52 ZBW	you still do .. let's go over to New York now one two zero correction ah .. (let's get) the right frequency .. one two five point five .. have a nice night.
		0120:59 RDO-2	twenty-five five switching.
		0121:40 RDO-2	New York FedEx fourteen heavy with you at seven thousand.
		0121:44 NYAPP	FedEx fourteen heavy New York approach roger .. proceed direct to Teterboro for the ILS two two right .. Newark altimeter three zero two three.
		0121:53 RDO-2	direct Teterboro .. three zero two three FedEx fourteen heavy.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0121:58 HOT-1	I don't have that in there anywhere but if you can just -		
0122:02 HOT-2	I'll put it in there .. TEB .. got it.		
0122:08 HOT-1	that's at just about Agnss .. I'll just .. I'll just head direct to that pretty much for right now.		
0122:14 HOT-2	there's the ah -		
0122:15 HOT-1	and when you get it in there we'll .. you don't have to do that. this .. Agnss and Teterboro are just about the same spot. direct there will work.		
0122:22 HOT-2	there it is.		
0122:24 HOT-2	nav's available.		
0122:25 HOT-1	okay, you can make it direct Agnss .. be alright .. I'm sorry. that's close enough .. it's .. they're right on top of each other.		
0122:45 HOT-2	oh, okay yeah.		
		0122:49 NYAPP	FedEx fourteen heavy descend and maintain three thousand.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0122:52 RDO-2	three thousand now FedEx fourteen heavy.
0122:56 CAM	[sound of several clicks]		
0122:57 HOT-1	three thousand .. ah .. Agnss will be alright .. direct Agnss.		
0122:58 HOT-2	three thousand ... and kill Teterboro?		
0123:02 HOT-1	yeah, you don't need that. it's pretty much the same spot. okay, now (I'm in NAV).		
0124:16 HOT-2	what's that ATIS ..... Kilo ... there's one ten seventy-five .. one ten seventy-five.		
0124:28 HOT-1	[sound of human whistling]		
0125:04 CAM	[sound of tone and verbalized "altitude" from the CAWS repeats twice]		
0125:08 HOT-2	and four for three.		
0125:09 HOT-1	alright.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0125:10 HOT-2	why .. why does it have that amber altitude up there?		
0125:12 HOT-1	say again.		
0125:14 HOT-2	see that .. see that amber altitude right below the ... on your side there.		
0125:16 HOT-1	ah your .. yeah I've got .. we've got a difference .. I got twenty .. thirty twenty-three .. you got thirty twenty-seven. he gave twenty-three a minute ago to somebody. we'll just verify it when we get down there.		
0125:23 HOT-2	oh okay .. I'm sorry.		
0125:26 HOT-1	that's what that's all about.		
0125:26 HOT-2	yeah sure.		
0125:34 HOT-2	(and) coming up on three thousand.		
0125:34 HOT-1	I could be wrong. maybe he gave that to somebody else going someplace else .. but I heard a three zero two three in there awhile ago.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0125:38 HOT-2	yeah ..... oh, I think you're right .. I think I forgot .. failed to set it.		
0126:17 HOT-1	I'll take slats extend.		
0126:20 HOT-2	slats extend.		
0126:21 CAM	[sound of several clicks, similar to that of the flap/slat handle movement]		
0126:21 HOT-1	and well looks like we do an approach check.		
0126:25 HOT-2	(two are tuned there.)		
0126:32 HOT-2	want the approach check?		
0126:33 HOT-1	approach check, yes. I don't know if you heard me or not.		
0126:35 HOT-2	okay, briefing?		
0126:36 HOT-1	ah .. it's complete for twenty-two right.		
0126:39 HOT-2	altimeters?		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0126:41 HOT-1	I've got three zero two three set on this side.		
0126:43 HOT-2	three zero two three set on this side .. we'll .. we'll check again (with) the next controller there. okay minimums?		
0126:49 HOT-1	ah two eleven.		
0126:50 HOT-2	two eleven .. radios?		
0126:54 HOT-1	look tuned and identified.		
0126:55 HOT-2	tuned and identified .. approach checklist complete.		
		0127:24 NYAPP	FedEx fourteen heavy turn right heading one eight zero.
		0127:26 RDO-2	one eight zero FedEx fourteen heavy.
0127:34 HOT-1	one eighty.		
		0127:38 ATIS	Newark airport information Lima time zero four five one Zulu .. automated weather .. wind two five zero at five .. visibility one zero .. eight thousand scattered .. temperature two zero .. dew point one two ..altimeter three zero two four.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0127:59 NYAPP	[continuation of transmission to another aircraft] ... Newark altimeter three zero two three.
0127:59 HOT-2	the ATIS is calling three zero two four.		
0128:02 HOT-1	okay.		
0128:02 HOT-2	a there .. he just called three zero two three though.		
		0128:04 NYAPP	FedEx fourteen heavy .. descend and maintain two thousand .. advise field in sight.
		0128:08 RDO-2	two thousand .. will advise .. FedEx fourteen heavy.
0128:13 HOT-1	flaps fifteen.		
0128:14 HOT-2	flaps fifteen.		
0128:15 CAM	[sound of several clicks, similar to that of the flap/slat handle movement]		
0128:50 HOT-2	there's a beacon out there.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0128:51 HOT-1	I sure don't see it.		
0128:58 HOT-2	there's a beacon right out ... it's all white .. it's gonna go green again in a little bit.		
		0129:01 NYAPP	FedEx fourteen heavy .. the field's ah one o'clock and ah eight.
0129:05 CAM-?	it should be over here.		
		0129:05 RDO-2	fourteen heavy roger.
0129:07 HOT-1	I still don't have it.		
0129:08 HOT-2	the white strobes .. see the white strobes .. I don't know if that would .. if that's the end of the runway.		
0129:10 HOT-1	okay yeah .. got it .. got it .. it was sitting right here in the -		
		0129:12 RDO-2	and fourteen heavy's got the field in sight.
		0129:14 NYAPP	FedEx fourteen heavy .. cleared visual approach runway two two right .. contact Newark tower one one eight point three .. good day.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
		0129:20 RDO-2	eighteen three FedEx fourteen heavy switching.
0129:25 HOT-2	cleared the approach .. eighteen three.		
0129:32 HOT-2	there it is .. got it?		
0129:33 HOT-1	I got it.		
		0129:34 RDO-2	tower FedEx fourteen heavy is rolling final runway two two right.
0129:42 HOT-1	flaps twenty-eight.		
0129:44 HOT-2	flaps twenty-eight.		
0129:45 CAM	[sound of several clicks, similar to that of the flap/slat handle movement]		
		0129:45 EWR	FedEx fourteen heavy .. ah winds two five zero at five .. two two right cleared to land.
		0129:51 RDO-2	cleared to land two two right FedEx fourteen heavy.

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0129:55 HOT-2	flaps are at twenty-eight.		
0129:55 HOT-1	got a glide slope capture .. gear down .. before landing check.		
0129:58 CAM	[sound similar to that of landing gear being lowered]		
0130:01 CAM	[sound of click, similar to that of spoilers being armed]		
0130:02 HOT-2	max brakes.		
0130:03 HOT-1	max brakes will be fine.		
0130:05 HOT-2	if they work.		
0130:17 HOT-1	flaps thirty-five.		
0130:19 CAM	[sound of several clicks, similar to that of the flap/slat handle movement]		
0130:25 HOT-2	okay, spoilers are armed .. autobrakes?		
0130:30 HOT-1	okay, maximum .. looks like it's set.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0130:32 HOT-2	land .. landing gear down in four green.		
0130:34 HOT-1	down in four green .. flaps fifty.		
0130:36 HOT-2	flaps fifty.		
0130:36 CAM	[sound of several clicks, similar to that of the flap/slat handle movement]		
0130:41 HOT-2	flaps are fifty.		
0130:43 HOT-1	okay.		
0130:44 HOT-2	coming up on and -		
0130:45 HOT-1	coming off the autopilot.		
0130:48 HOT-2	flaps are fifty.		
0130:48 CAM	[sound of warble tone and verbalized "autopilot" from the CAWS]		
0130:49 HOT-2	before landing checklist is complete.		

INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0130:59 HOT-1	two and three on the reverse .. just in case I forget.		
0131:01 HOT-2	roger that .. two and three.		
0131:03 CAM	[sound of unknown click and chime]		
0131:03 CAM	[verbalized "one thousand" from the CAWS]		
0131:07 HOT-1	category one.		
0131:09 HOT-2	(got that.)		
0131:38 CAM	[verbalized "five hundred" from the CAWS]		
0131:40 HOT-2	alright .. cleared to land two two right.		
0132:03.00 HOT-2	there's (coming up) minimums.		
0132:05.85 HOT-2	okay, gear's down .. flaps are fifty.		
0132:09.58 HOT-2	brakes on max.		

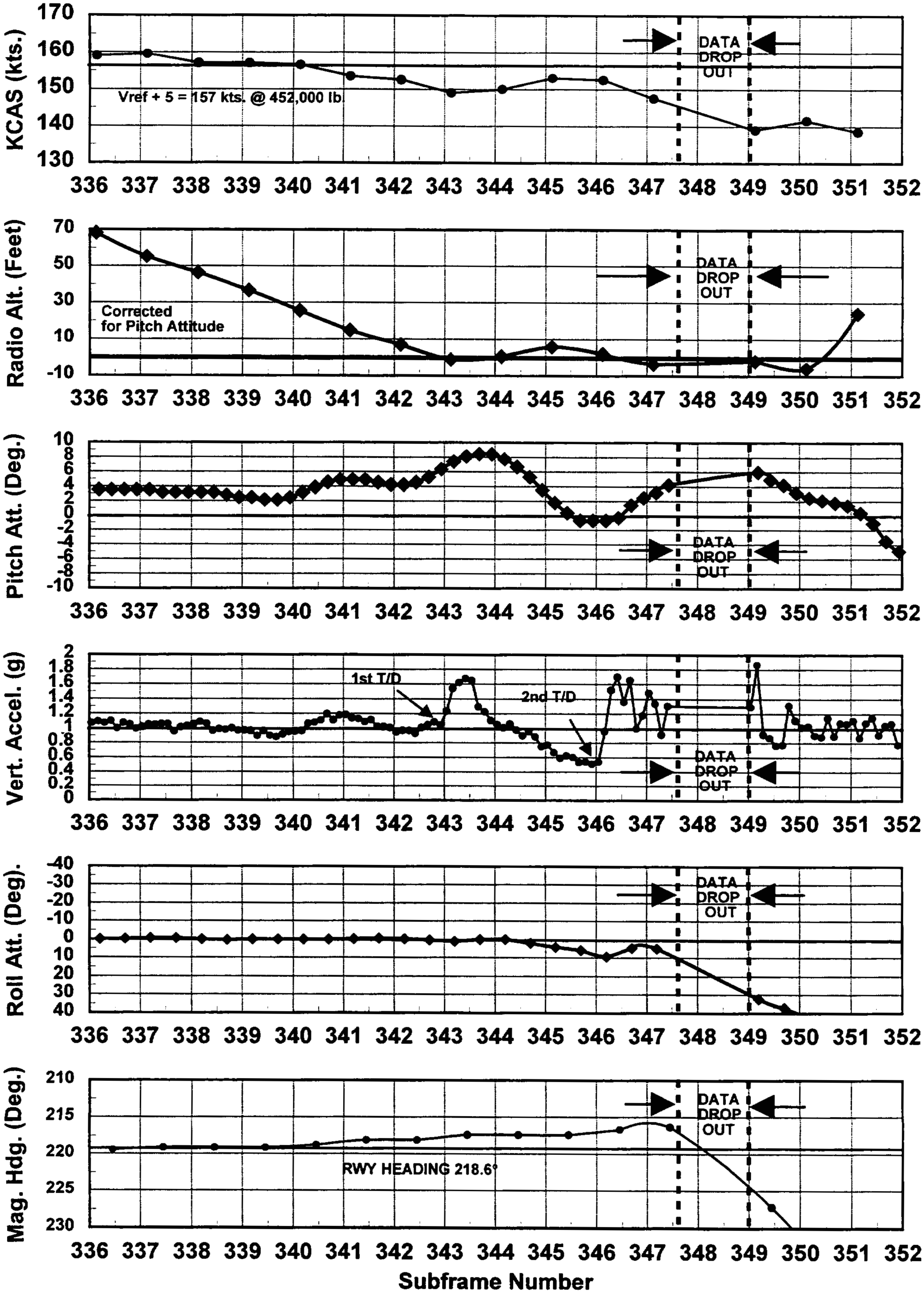
INTRA-COCKPIT COMMUNICATION		AIR-GROUND COMMUNICATION	
TIME and SOURCE	**CONTENT**	**TIME and SOURCE**	**CONTENT**
0132:09.65 CAM	[verbalized "one hundred" from the CAWS]		
0132:13.84 CAM	[verbalized "fifty" from the CAWS]		
0132:14.71 CAM	[verbalized "forty" from the CAWS]		
0132:15.72 CAM	[verbalized "thirty" from the CAWS]		
0132:16.55 CAM	[verbalized "twenty" from the CAWS]		
0132:17.67 CAM	[verbalized "ten" from the CAWS]		
0132:18.75 CAM	[sound of initial touchdown]		
0132:19.21 HOT-1	#.		
0132:20.26 CAM	[sound of increase in high frequency tone, similar to that of engine spool-up]		
0132:21.06 CAM	[sound of decrease in high frequency tone, similar to that of engine spool-down]		
0132:20.98 HOT-1	# damn it.		

INTRA-COCKPIT COMMUNICATION | **AIR-GROUND COMMUNICATION**

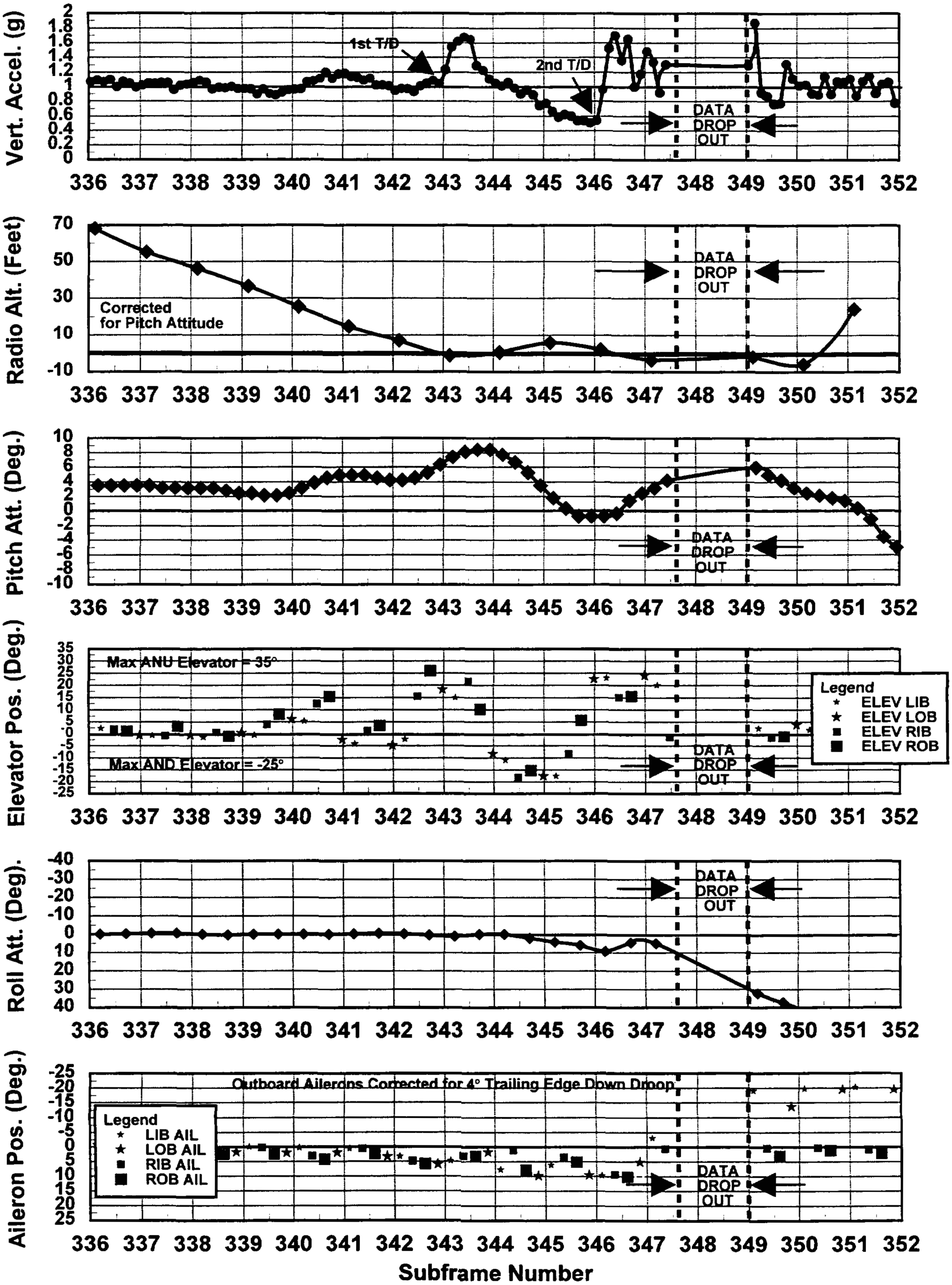
TIME and SOURCE	CONTENT	TIME and SOURCE	CONTENT
0132:21.56 HOT-2	jesus.		
0132:21.62 CAM	[sound of loud thump, similar to aircraft touchdown]		
0132:22.42 HOT-1	# damn it.		
0132:23.14 CAM	[0.31 second loss in CVR audio]		
0132:23.84 HOT-1	#.		
0132:24.43 HOT-1	oh #.		
0132:26.05 CAM	[verbalized "tire failure" repeats twice]		
0132:26.43 HOT-2	# damn it (damn it.)		
0132:27.42 CAM	[sound of metallic break-up]		
0132:28.83 CAM	[end of recording]		

5.2 FDR Data Plots

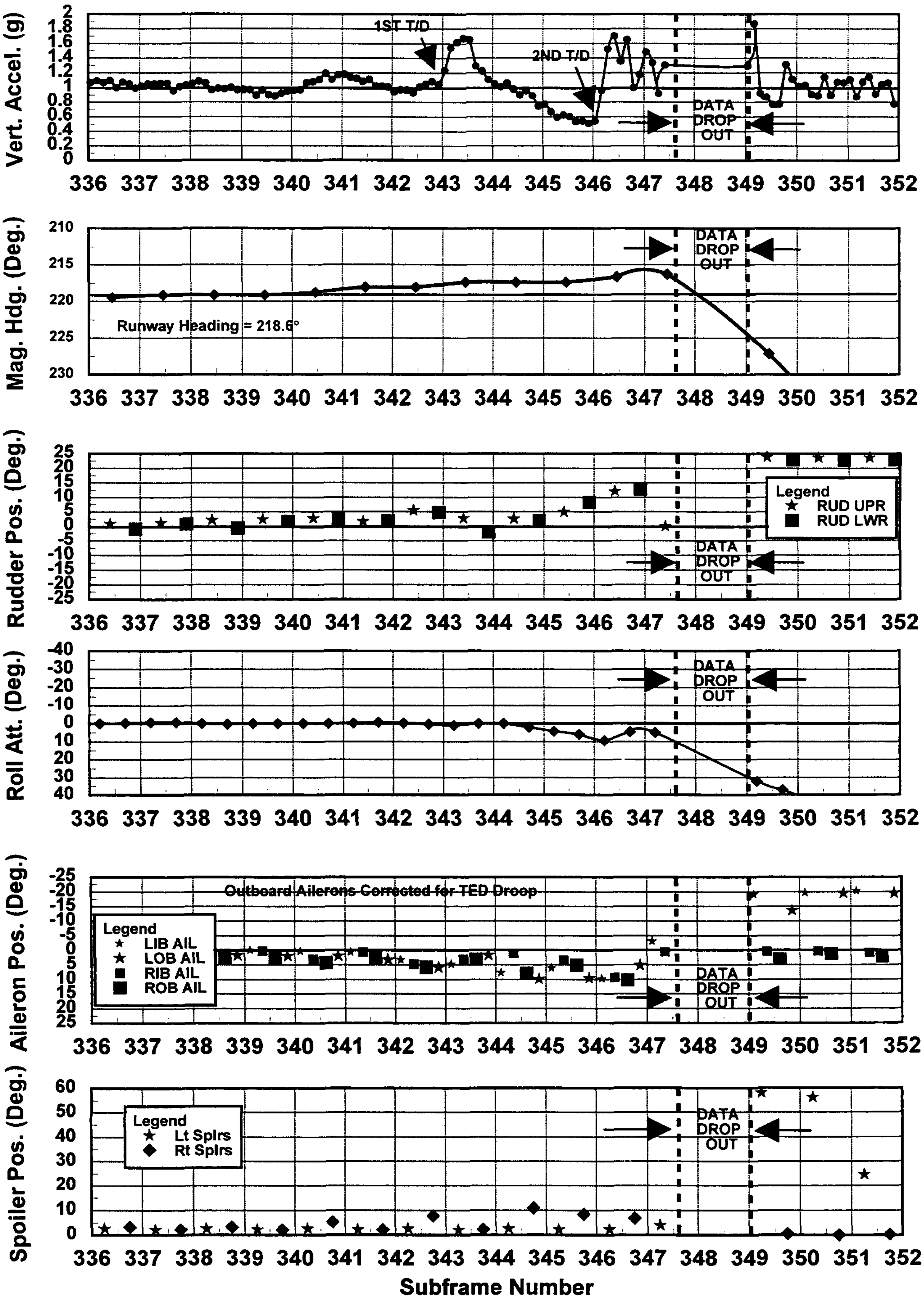
FEDEX MD-11, KEWR, 31 JULY 1997



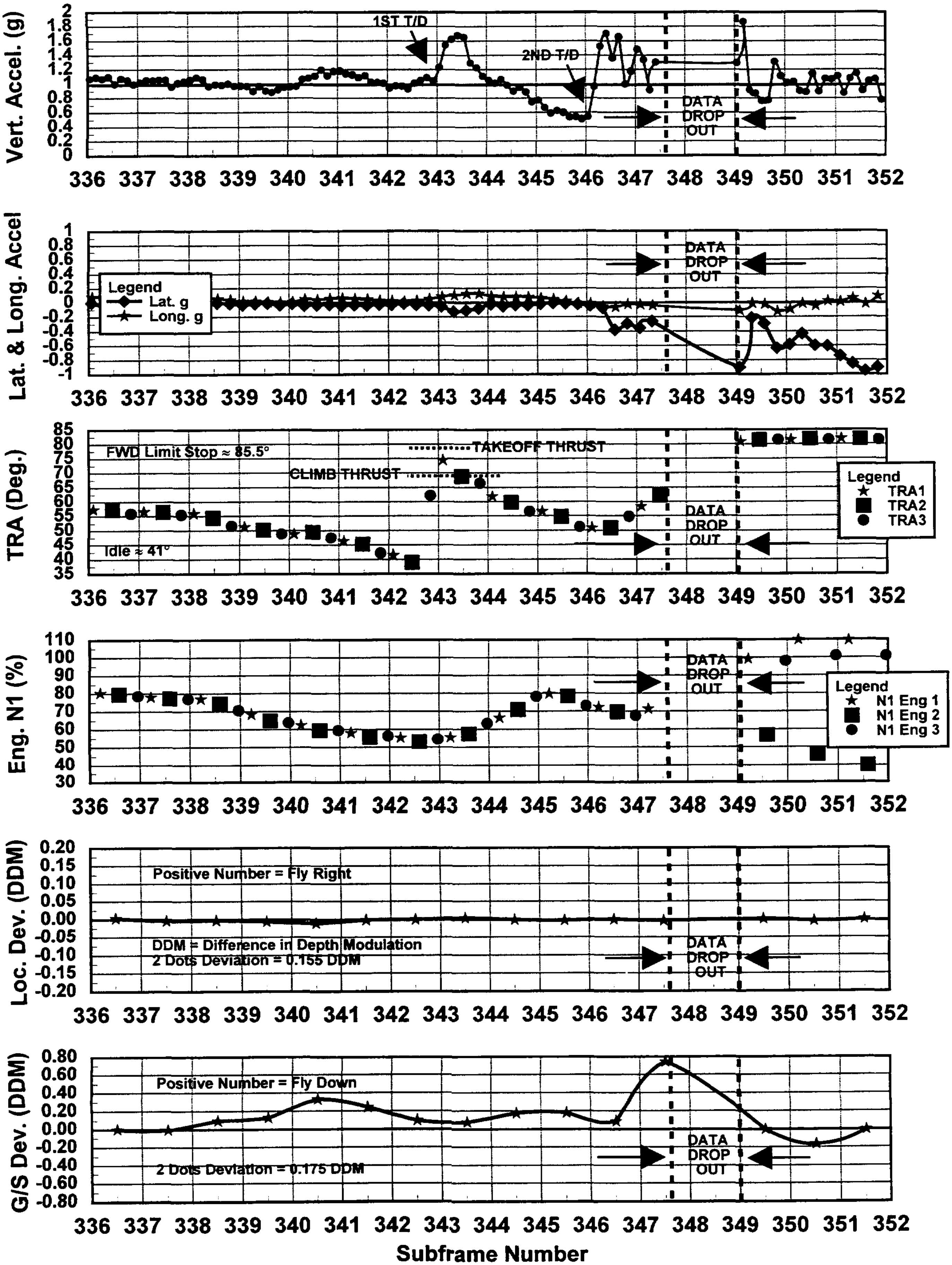
FEDEX MD-11, KEWR, 31 JULY 1997

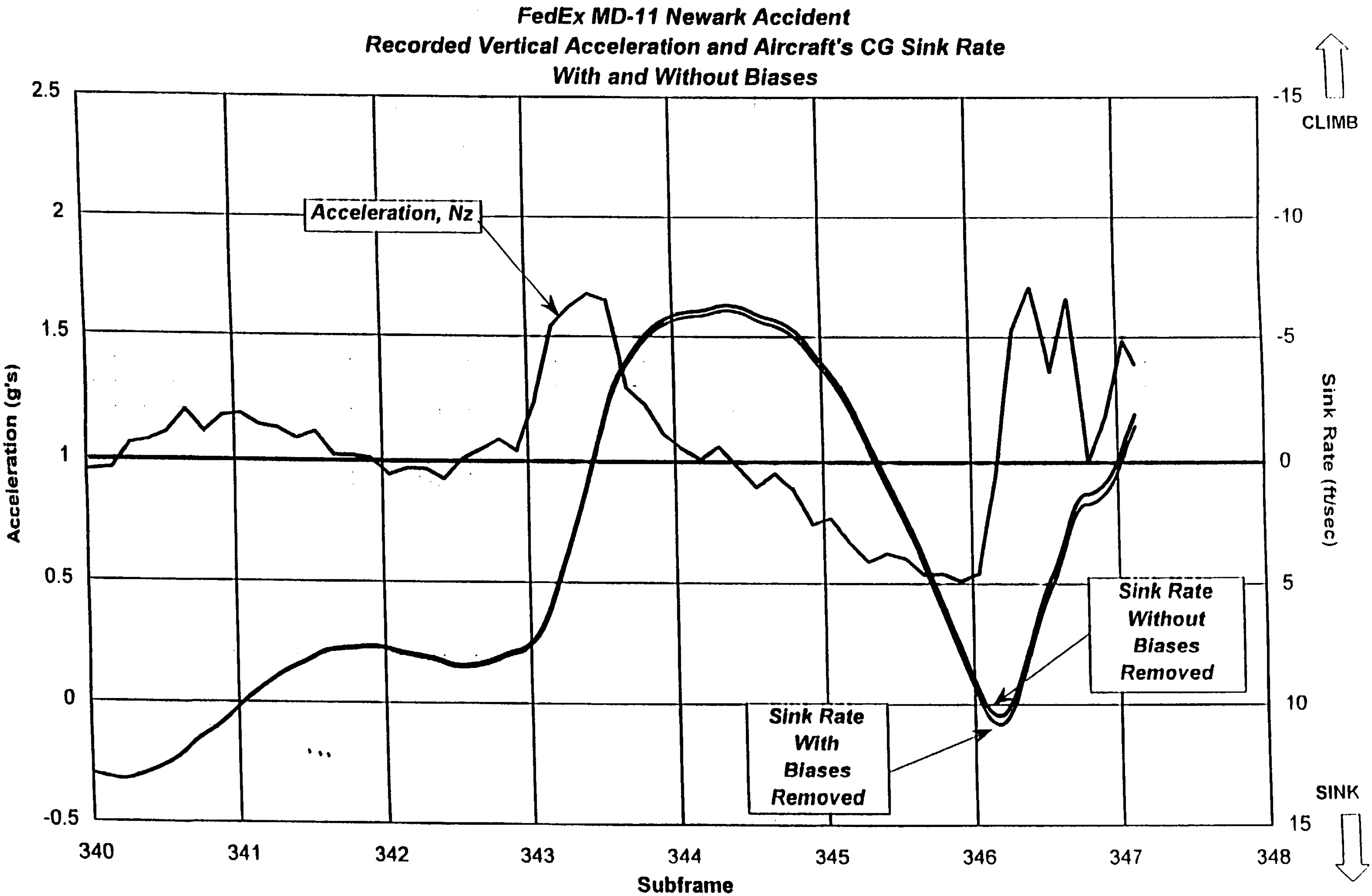


FEDEX MD-11, KEWR, 31 JULY 1997

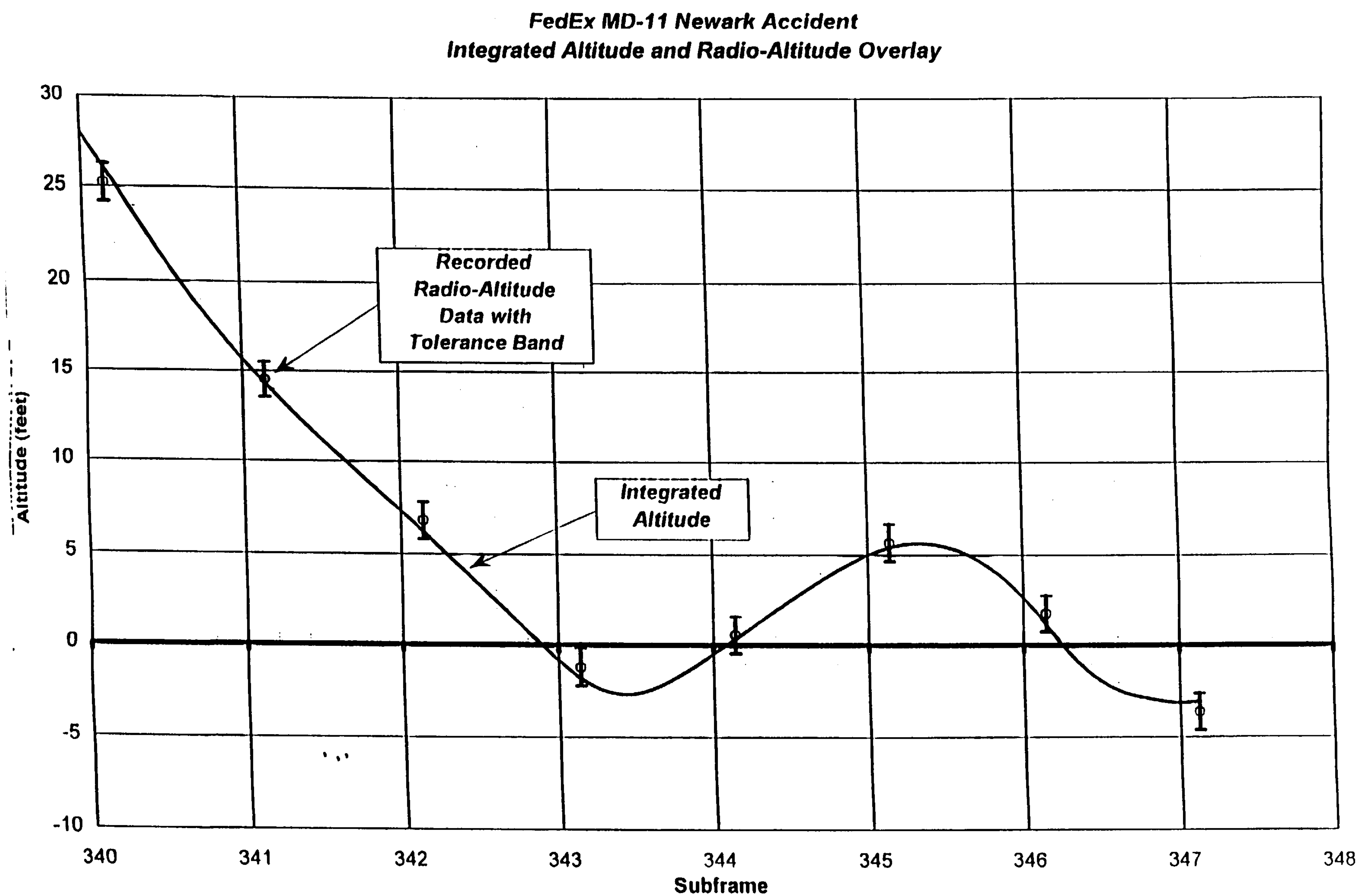


FEDEX MD-11, KEWR, 31 JULY 1997





FedEx MD-11 Newark Accident
Recorded Vertical Acceleration and Aircraft's CG Sink Rate
With and Without Biases
Acceleration, Nz
Sink Rate Without Biases Removed
Sink Rate With Biases Removed
Acceleration (g's)
Sink Rate (ft/sec)
CLIMB
SINK
Subframe
2.5
2
1.5
1
0.5
0
-0.5
-15
-10
-5
0
5
10
15
340
341
342
343
344
345
346
347
348


FedEx MD-11 Newark Accident
Integrated Altitude and Radio-Altitude Overlay
Recorded Radio-Altitude Data with Tolerance Band
Integrated Altitude
Altitude (feet)
30
25
20
15
10
5
0
-5
-10
340
341
342
343
344
345
346
347
348
Subframe

5.3 Logged FCC Faults (NVM)

FAULTS LOGGED ON ACCIDENT FLIGHT: FCC S/N 0549					
Fault No.	**Fault Message**	**Failed Monitor(s)**	**Time**	**Altitude**	**KCAS**
1	CFDIU Failure	GMT INV BARO COR ALT INV CAS INV DATE INV FLT NO. INV	0000	0	0
2	CFDIU Failure	CFDS CMDS INV	0530	1200	162
3	D/Land Avail. Fail.	P ATT RATE INV	0531	-16	152
4	D/Land Avail. Fail.	P ATT RATE INV LOC DEV INV G/S DEV INV	0532	-32	145
5	LSAS Failure	P ATT RATE INV	0532	0	141
6	Continuous Test Failure	AIL MOD LVDT AIL RAM LVDT EL MOD LVDT EL RAM LVDT RUD MOD LVDT RUD RAM LVDT	0532	-32	135
7	Single Land Availability Failure	P ATT RATE INV X-TRK ACC INV LOC DEV INV G/S DEV INV TUNING LOST	0532	0	141
8	Go around Availability Failure	Y-RATE INV VERT ACC INV P ATT RATE INV R ANGLE INV LONG ACC INV LAT ACC INV P ANGLE INV IRS VERT SPD INV PRESS ALT INV TAS INV CAS INV MACH INV RA INV FLAP POS INV AOA TMM INV	0532	-32	135

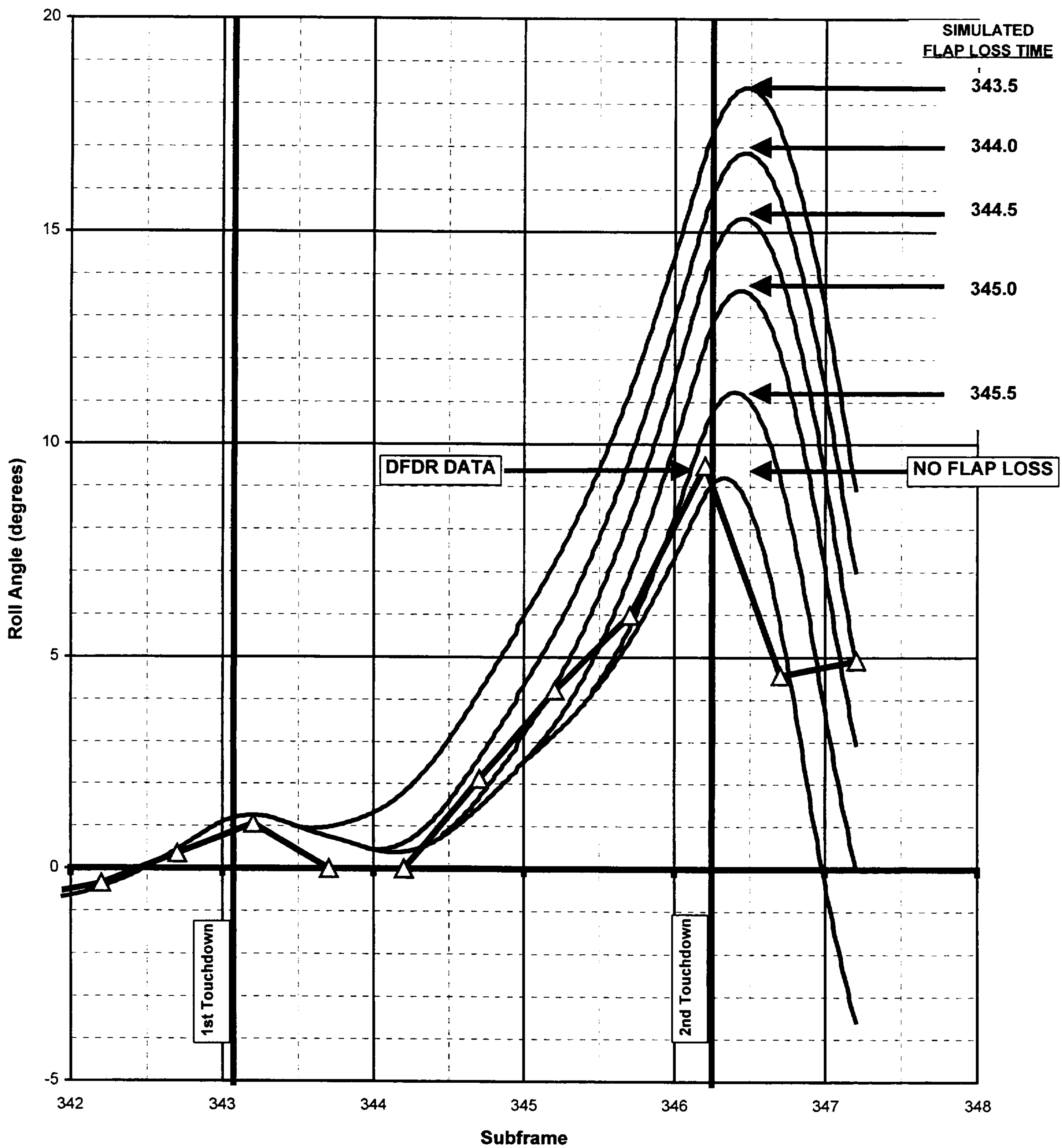
BOEING

FAULTS LOGGED ON ACCIDENT FLIGHT: FCC S/N 0326					
Fault No.	Fault Message	Failed Monitor(s)	Time	Altitude	KCAS
1	CFDIU Failure	CFDS CMDS INV	0530	1200	162
2	D/Land Avail. Fail.	P ATT RATE INV	0531	-16	148
3	LSAS Failure	P ATT RATE INV	0532	-32	145
4	Yaw Damper Fail.	RUD MOD LVDT	0532	0	141
5	Contin. Test Fail.	RUD MOD LVDT	0532	0	141
6	S/Land Avail Fail.	P ATT RATE INV	0532	-32	145
7	D/Land Avail. Fail.	LOC DEV INV G/S DEV INV	0532	-32	145

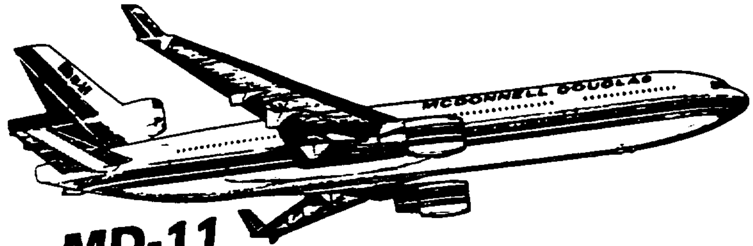
5.4 Right Inboard Flap Departure

FEDEX MD-11 Newark Accident - Inboard Flap Departure Investigation

Aircraft Roll Response Following Simulated RIB Flap Failures in Comparison to DFDR Data



5.5 Know Your MD-11 Letter



Know Your MD-11

LETTER NO. 3
DATE: April 14, 1993

TO: ALL MD-11 OPERATORS

FROM: FLIGHT OPERATIONS CUSTOMER SERVICE DOUGLAS AIRCRAFT COMPANY

SUBJECT: LANDING CHARACTERISTICS AND TECHNIQUES

This "Know Your MD-11" Newsletter is compiled and published by Douglas Flight Operations Customer Service. The material contained herein was accurate at the time of publication, and it is intended to provide information only. Should conflicts arise between this document and official manuals i.e., the Aircraft Flight or Flight Crew Operating Manuals, the official manuals are the final authority and shall supercede the data in this document.

Our new "Know Your MD-11" Newsletter will be issued periodically, on an as-needed basis. If you find it useful, or if you have a subject you would like discussed in a future issue, please contact Art Torosian at the address below; we would like to hear from you.

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INTERNAL MAIL CODE 94-26
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Long Beach, California 90846

From time to time we receive requests from our customers, particularly new operators, for advice on how to get good, consistent, safe landings with their new airplane. We have pooled the collective experience of our Douglas pilots, and offer the following:

The landing characteristics of the MD-11 are very conventional for an aircraft of its size and weight. Flight controls are responsive, well balanced and predictable, and with a little practice, pilots are able to achieve consistently smooth, well controlled landings very close to the desired point of touchdown.

The following is a phase-by-phase discussion of proven approach/landing techniques which may help you to achieve consistency; if you have questions or advice that you would like to see included in future issues, please let us hear from you.

MD-11 LANDING CHARACTERISTICS AND TECHNIQUES

Visual Approach

The aircraft should be stabilized in the final landing configuration, on a descent flight path and on speed, with appropriate wind and gust corrections applied to V_{ref} by 1000' AGL. If the aircraft is not stabilized by 500 feet a missed approach should be executed. Rate of descent should not exceed 1000 fpm below 1000'. The visual aimpoint to provide a threshold clearance height of 47' on a 3.0 degree glideslope should be approximately 1700'. This will provide a touchdown point approximately 900' from the threshold without a flare. Do not deviate from the visual glidepath in an attempt to touch down early.

Flare

Auto throttles will begin to retard after passing 50', and a slight flare should be initiated between 30 to 40 feet (approximately 2°). The aircraft should touch down in the touchdown zone. The technique described above will result in a touchdown slightly below V_{ref}. Do not hold the aircraft off in an attempt to achieve a smooth landing. This will result in a long touchdown, higher than necessary braking forces, a higher pitch attitude and reduced tail strike margin. The aft fuselage will contact the runway at approximately 10° pitch attitude with the struts compressed.

Touchdown

At touchdown, with main wheel spin up, assure ground spoiler deployment and prepare to counter any pitching tendency as the spoilers extend. This will require the pilot to fly the nosewheel to the ground.

Rollout

As the nose is lowered to the runway, reverser deployment may be initiated by selecting reverse on all three engines simultaneously. A momentary pause will be encountered at the interlock stop on numbers 1 and 3 engines, and then reverse thrust may be selected to the desired level. Number 2 engine will provide only idle reverse thrust until nosewheel strut compression. For a normal landing, at 80 KIAS, smoothly move the reverse thrust levers toward the reverse idle detent, so as to be at reverse idle by 60 KIAS. Pause at reverse idle for 2 seconds prior to stowing the reversers.

General Discussion: factors warranting more detailed discussion

Center of Gravity

The nominal CG range for landing is 25 - 27% MAC. Pitch control forces in the flare are light to moderate, and following initial ground spoiler deployment (30°) at Main Wheel Spin-up, a mild pitch up tendency will be evident. This characteristic is easily controlled; flight crews should be trained to "fly" the nose wheel to the runway surface, and to apply light forward yoke pressure thereafter to ensure that the nosewheels remain in contact with the runway. A mild pitch up may also be detectable when the final ground spoiler extension occurs (60°) at nosegear strut compression. Light forward yoke pressure will counteract this tendency, and will enhance directional control as well.

Landing with an aft CG, 27-30% MAC, will exhibit lighter pitch control forces in the flare, and may be accompanied by a more pronounced pitch up tendency on landing. The tendency of the aircraft to float while flaring in ground effect is more noticeable at aft CG, especially at light gross weights. Crews should be cautioned to be sensitive to CG, and to avoid holding-off to achieve a soft touchdown. Such a technique can result in a long float, excessive pitch attitude, and possibly a firm, drop-out type landing which could strike the aft fuselage.

Landing with a more forward CG (22-24°) requires more nose up pitch trim and slightly heavier pitch control forces in the flare; crews sensitive to this forward CG will anticipate these forces and adjust accordingly. Pitch-up on spoiler deployment may be less evident.

At the extreme forward end of the landing CG envelop, full or near-full nose up stabilized trim may be required for a stabilized final approach. Landings forward of 15% MAC are not likely in revenue service. The MD-11 has sufficient stabilizer trim to trim out all elevator forces for on-speed approaches at any CG setting within the normal landing envelope. LSAS trims out any sustained elevator deflection during hand flying, as long as the control yoke force is less than 2 pounds. At 100 feet AGL the LSAS disengages, and any nose-up elevator command would be washed out within 1 second, and a slight drop in the nose may be observed just before the flare. From a practical standpoint, this nose lowering would be barely perceptible, and of little consequence to the flare and touchdown.

These additional guidelines are emphasized:

1. Autothrottles should be used for all landings. The reduction of power, starting gradually at about 50 feet and continuing through the flare, complements a smooth transition to a well controlled and timely touchdown. The Autothrottle will continue to move the throttles to idle if not already in idle at touchdown.

2. Pilots should not trim the stabilizer during the flare. Such activity may contribute to float, a nose high touchdown attitude, a possible tail strike, and may aggravate any existing pitch up tendency after touchdown.

3. Experience has shown that approaches which result in large pitch deviations, and which never achieve true speed and glide path stability are much more likely to produce unpredictable landings; hold-offs, floats, hard touchdowns, strong rebounds and tail strikes. Such approaches make it nearly impossible to establish a proper crosswind correction, and are especially risky on contaminated or slippery surfaces. A destabilized approach is a compelling reason to initiate an early go-around.

LANDING ON WET OR SLIPPERY SURFACES

On a wet and/or slippery surface every effort should be made to ensure that reverse thrust is applied symmetrically across all three engines, and crews should be trained to carefully monitor any tendency for the aircraft to develop a skid when the surface is slippery. Should a skid condition develop, thrust should be brought to idle reverse on all three engines while the skid is corrected. When a limited amount of runway friction is available, reduced braking may improve the cornering capability of the aircraft, and with the use of rudder pedal nosewheel steering, help correct the skid. Sustained high reverse thrust in a skid will provide a force which can literally back the airplane off the downwind side runway surface.

INTERRUPTING A SYSTEMS TEST

Each of the three aircraft systems, Air, Hydraulics and Fuel, has a specified test routine to be accomplished by the flight crew before flight, usually during cockpit preparation. In examining the causes of instances in which one of these tests has failed, we have learned that while some of the failures revealed genuine system faults, many did not. Often the failure was the product of some flight crew action which unwittingly interrupted a test-in-progress.

To review, each of these systems follow a prescribed test routine which is not tolerant of disruption; such as, timing of certain activities, verification of pressure and flow checks, and things of that sort. Any conflicting demand which is made on a system during the test will cause the test to fail. In the cases of the Air and Hydraulics Systems tests, the consequences are not too disruptive; the crew can remove the conflicting demand, cycle the system to manual and back, and reinitiate the test. In the case of fuel, however, the disruption can be exasperating; consider a typical scenario:

a. A large load of fuel is being uploaded requiring, at some pumping stations, as much as an hour or more to accomplish.

b. This is the first refueling after landing, so a full Fuel System Test is initiated automatically when the fueling operation has been completed; the test may take up to 9 minutes.

c. With all flight preparations complete, and waiting only on the refueling operation, the crew requests a Pushback as soon as it is done.

d. Pressing to keep on schedule, the crew then initiates an engine start while the Fuel System Test is still in progress, and causes the test to fail.

With a "FUEL SYSTEM TEST FAIL" Alert displayed, the only action that can get the airplane back into a dispatchable status is to shut down all of the engines and have the ground crew run the test again. The ensuing delay usually means a missed departure slot, and often a protracted wait for a new one.

In an effort to reduce such occurrences, Douglas has shortened the time required to complete the Fuel System Test from 14 to approximately 9 minutes, and has made it a once-per-landing event, rather than one which occurs after every refueling. A last minute top off, for instance, will not initiate another test if a good one was performed after the initial fueling.
In summary, it is important to know the nature of the system self tests; such that any conflicting demand which is made on one of the aircraft systems while a test is in progress will always produce a failed test and a probable delay.

FUEL OFF SCHEDULE ON THE GROUND

There may be occasions when Ground Service or Maintenance refuel the airplane in a manner which may cause the FUEL OFF SCHEDULE alert to appear. This usually occurs as a result of testing a pump, exercising a valve etc. during the refueling operations. For whatever reason, if the flight crew finds the FUEL OFF SCHEDULE Alert displayed after refueling, usually no action will be required other than to call up the Fuel Synoptic. If the Fuel System Controller (FSC) is operating in automatic, it will take but a few minutes for the controller to automatically reconfigure the fuel distribution to normal, once the refueling has been completed. This will be evident on the Synoptic. If the system is operating in manual, then the crew should redistribute the fuel manually. In any case, it would be a good idea to question the ground staff to as to how the fuel happens to be off schedule.

PAB/hfg
knowmd#3

5.6 Excerpts from Flight Operations Seminar

Landing Techniques

FLIGHT OPERATIONS

3-TTPG-14

Prerequisites of a Good Landing

- GOOD SPEED CONTROL IS ESSENTIAL FOR A GOOD APPROACH AND LANDING
- A STABILIZED APPROACH IS ESSENTIAL FOR A GOOD LANDING
- THE FLARE IS THE CRITICAL POINT IN A LANDING
- THE CORRECT USE OF THE CONTROLS IS ESSENTIAL TO THE APPROACH, TOUCHDOWN AND IMMEDIATELY THEREAFTER

CA3194.01
3-MILR-1

Approach and Landing Speed Control

- THE AUTOTHROTTLES PROVIDE EXCELLENT SPEED CONTROL DURING THE APPROACH AND LANDING
- APPROACH SHOULD BE AT Vref. PLUS ANY WIND ADDITIVE
- THE AUTOTHROTTLES RETARD AT 47 FEET RADIO ALTITUDE WHICH RESULTS IN A TOUCHDOWN AT Vref. IF THE FLARE IS NOT EXTENDED. IF THE FLARE IS EXTENDED, SPEED WILL REDUCE AND THE PITCH ATTITUDE BECOMES ABNORMALLY NOSE UP. THIS RESULTS IN A TOUCHDOWN IN A NOSE UP ATTITUDE WITH UP ELEVATOR

CA3194.02
3-MILR-2

Stabilized Approach

- THE FLIGHT DIRECTOR PROVIDES GUIDANCE TO ENABLE THE PILOT TO FLY A STABILIZED ILS APPROACH DOWN TO THE FLARE POINT
- FLIGHT PATH ANGLE SET TO -3° OR VERTICAL SPEED SET TO -600 FEET PER MINUTE HELPS AS A REFERENCE DURING A VISUAL APPROACH
- THE STABILIZED FLIGHT PATH SHOULD BE FLOWN TO CROSS THE THRESHOLD AT ABOUT 50 FEET
- THE FLARE MANEUVER STARTS BELOW 50 FEET FROM THE STABILIZED APPROACH

CA3194.03
3-MILR-3

The Flare

- THE PILOT SHOULD GET READY TO FLARE WHEN THE RADIO ALTITUDE CALL OF 50 OCCURS

- DO NOT FLARE ABOVE 40 FEET. IDEALLY, THE FLARE SHOULD BEGIN AT THE 30 CALL BY INCREASING THE PITCH ATTITUDE BY 2° TO 3°

- THE CADENCE OF THE RADIO ALTITUDE CALL-OUTS 50 40 30 SHOULD BE EVENLY SPACED. THE INTERVAL 30 TO 20 SHOULD BE LONGER AND THE INTERVAL 20 TO 10 SHOULD BE LONGER STILL

CA3194.04
3-MILR-4

Touchdown

- IDEALLY, THE PITCH ATTITUDE SHOULD BE APPROACH +2.5° BELOW 10 FEET FOR A SMOOTH TOUCHDOWN
- THE CONTROL COLUMN BACK PRESSURE CAN BE RELAXED BELOW 10 FEET FOR A SMOOTH TOUCHDOWN

CA3194.05
3-MILR-5

Use of Controls

- SMOOTH FLIGHT IS THE RESULT OF MINIMAL USE OF THE CONTROLS TO PERFORM THE REQUIRED MANEUVER

- IN THE FLARE, THE CONTROL USED SHOULD BE SMOOTH

- AT TOUCHDOWN, THE TENDENCY TO PITCH UP IS PROPORTIONAL TO THE AMOUNT OF UP ELEVATOR USED. IF SOME DOWN ELEVATOR IS APPLIED AT OR IMMEDIATELY AFTER TOUCHDOWN, THERE IS NO PITCH-UP!

CA3194.06
3-MILR-6

Common Error

- THE MOST COMMON MISTAKE IS TO START THE FLARE AT 50 FEET AND GET INTO THE LANDING ATTITUDE AT 20 FEET. THEN PUSH THE CONTROL COLUMN FORWARD TO RESTART THE DESCENT - WHILE THE SPEED DECAYS - AND FLARE WITH UP ELEVATOR INPUT TOUCHING DOWN HARD WITH UP ELEVATOR - GUARANTEEING PITCH-UP

CA3194.07
3-MILR-7

MD-11 Landing Technique

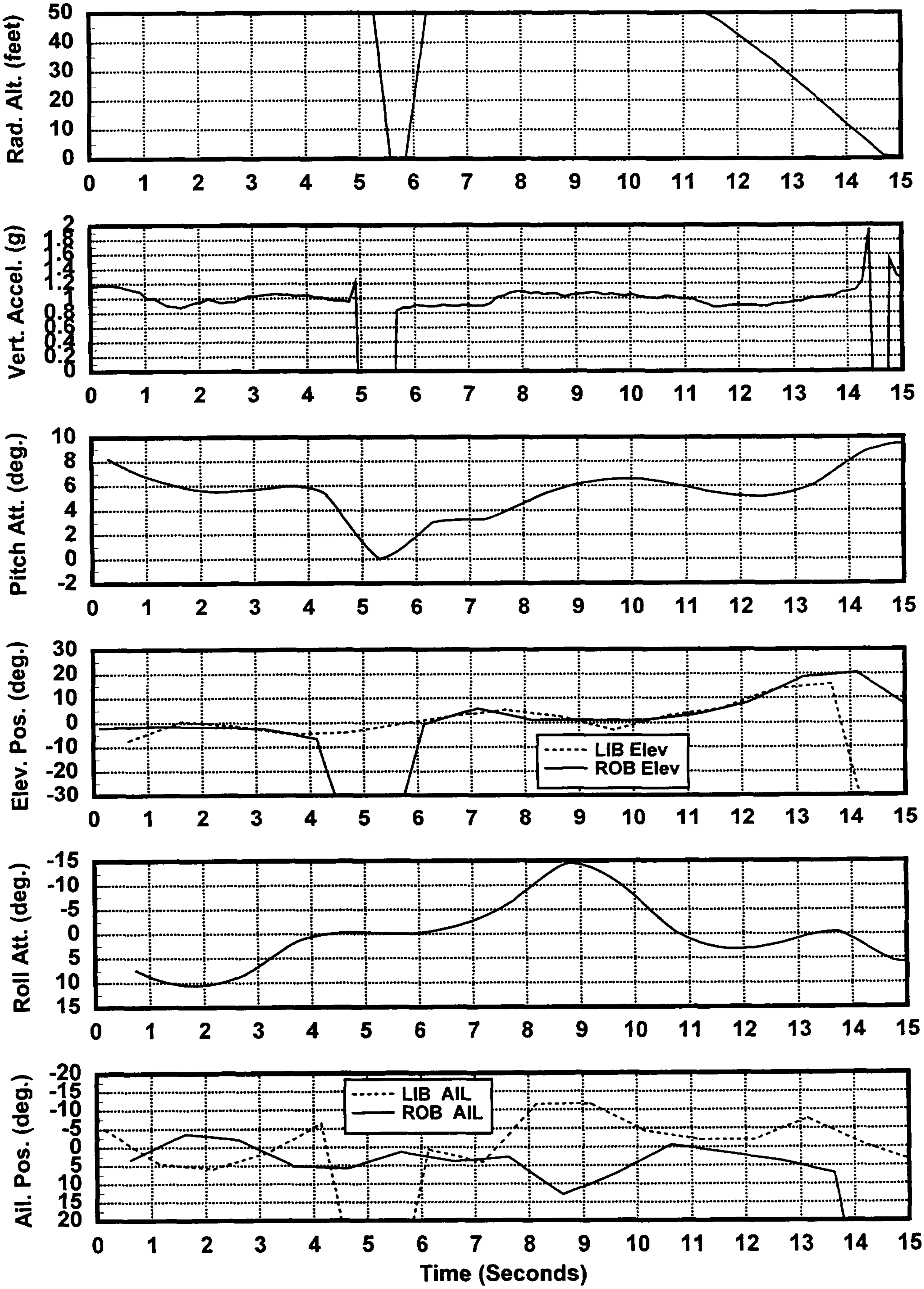
Summary

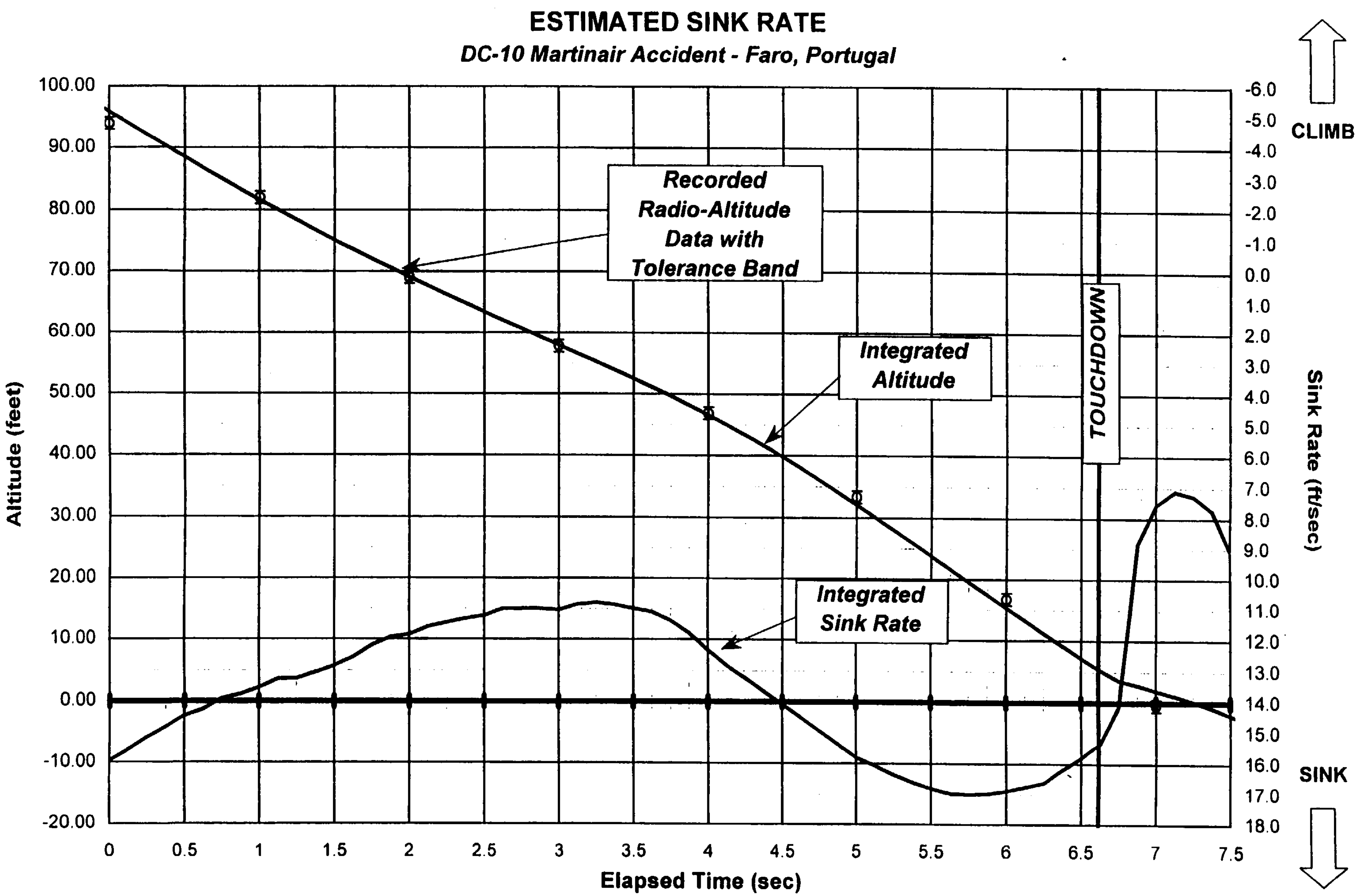
- STABILIZE SPEED - USE AUTOTHROTTLES
- STABILIZE FLIGHT PATH - USE FLIGHT DIRECTOR (OR AUTOPILOT)
- MAINTAIN DESCENT THROUGH 50 AND 40 FOOT CALLOUT UNLESS SINK RATE IS HIGH
- FLARE WITH 2.5° OF PITCH CHANGE AT 30 FEET
- ARRIVE BELOW 10 FEET FLARED. THEN RELAX BACK PRESSURE TO TOUCHDOWN
- CONTINUE FORWARD CONTROL COLUMN PRESSURE AFTER TOUCHDOWN TO GENTLY LOWER NOSE WHEELS TO THE RUNWAY AND AVOID PITCHUP

CA3194.08
3-MILR-8

5.7 Martinair Faro Data

MARTINAIR DC-10, FARO, 21 DEC. 1992




ESTIMATED SINK RATE
DC-10 Martinair Accident - Faro, Portugal
Recorded Radio-Altitude Data with Tolerance Band
Integrated Altitude
Integrated Sink Rate
TOUCHDOWN
CLIMB
SINK
Altitude (feet)
Sink Rate (ft/sec)
Elapsed Time (sec)
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
-10.00
-20.00
-6.0
-5.0
-4.0
-3.0
-2.0
-1.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
15.0
16.0
17.0
18.0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
5.5
6
6.5
7
7.5

5.8 TWA JFK Data

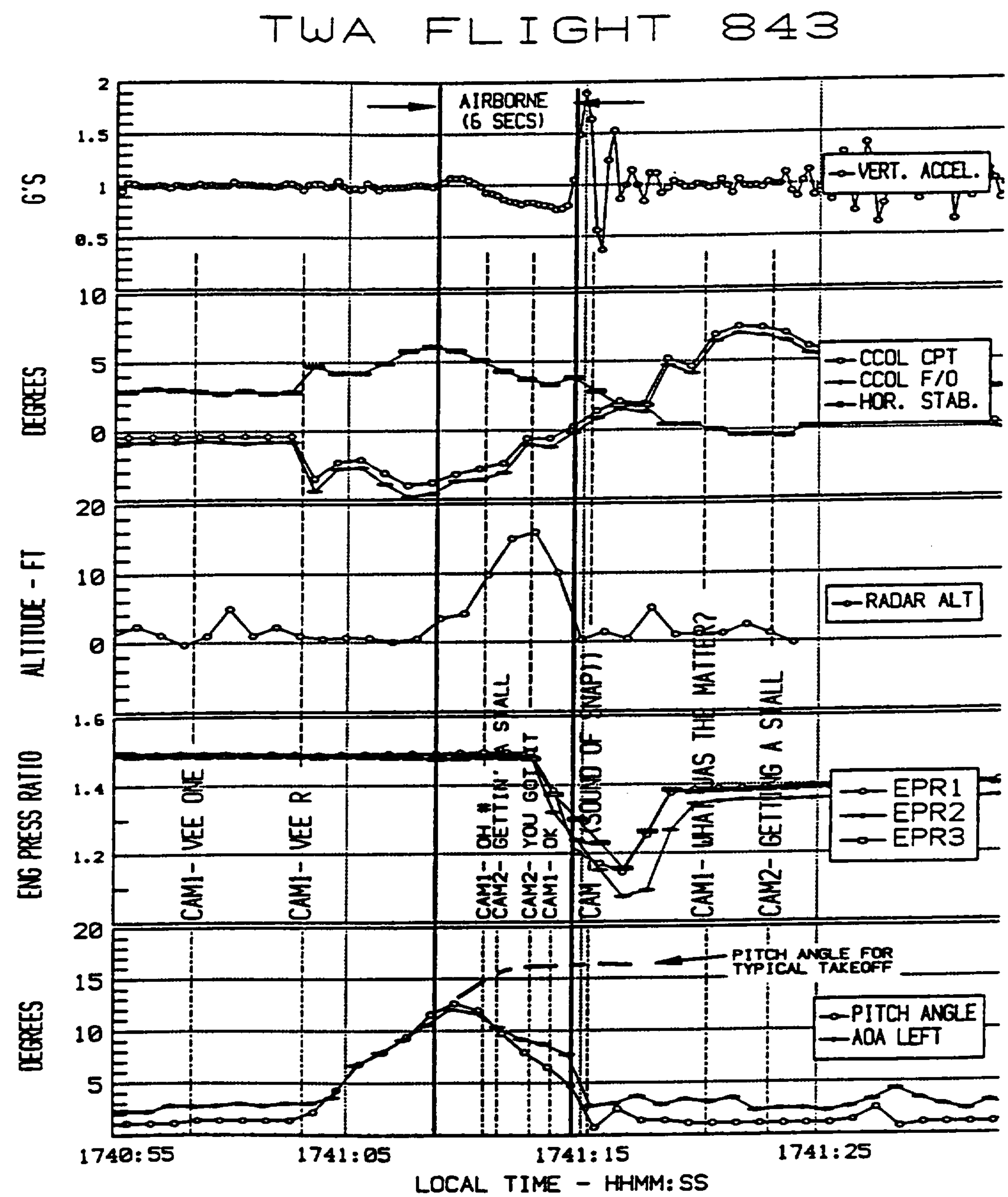


Figure 13.--Flight performance data.

5.9 Energy, Airplanes, and Landing Gear

BOEING

Energy, Airplanes and Landing Gear....

A few observations on energy and work and calculating such:

Conservation of Energy

Energy is "conserved" i.e. it doesn't mysteriously appear or disappear. For example, if I place an object on a spring scale it "sinks" through a certain distance (lost gravitational potential energy) while a spring force builds up (energy "stored" in the spring). If I place the object on the scale carefully, so that its initial velocity is zero and it doesn't drop through a distance before it contacts the scale, then the initial energy state can be accurately characterized simply by calculating the object's gravitational potential energy. When the object has finished "sinking", and has come to rest, it has a new (reduced) gravitational potential energy state. The difference between the before-and-after gravitational potential energy states must be accounted for. The great majority of the difference shows up as stored energy in the spring; an ever-so-miniscule amount of energy is lost by heat.

Work

"Work" is a term used to describe energy as it is being transformed from one form to another. It has the same units as energy and can be used in an conservation-of-energy equation when you are showing "where the energy went". For example, if I carry a big rock up a hill I have increased its gravitational potential energy by a certain amount. To effect this increase I have burned my calories; the amount of energy transferred from my body to the (increased gravitational potential energy of the) rock is referred to as the amount of "work" I did. Likewise, if I am holding an object against the force of a spring and then release it, the spring accelerates the object to some velocity. The amount of stored energy in the spring that is converted to energy-of-motion (kinetic energy) is referred to as the "work" done by the spring.

Work can be calculated as:

Fd where F is the force applied
d is the distance over which the force acts (measured in the direction the force is acting)

If the force is varying in direction or magnitude, then the total work must be calculated by integration (or by totaling small increments of distance wherein the force remains essentially constant)

BOEING

Potential Energy

Potential energy is a term most often associated with the earth's gravitational pull. If something is up in the air, and you remove whatever is holding it there, it will fall ("releasing" potential energy). An object's gravitational potential energy is calculated as:

Mgh where M is the object's mass
g is the acceleration of gravity, and
h is the height of the object above the ground

Since an object's weight (on earth) is equal to its mass times the acceleration of gravity, its gravitational potential energy can also be expressed as:

Wh where W is the object's weight

Kinetic Energy

Kinetic energy is "energy of motion". An object's kinetic energy if it is moving (translating) but not rotating is calculated as:

$\frac{1}{2}Mv^2$ where M is the object's mass, and
v is the object's velocity

The object's kinetic energy if it is rotating but not translating is calculated as:

$\frac{1}{2}I\omega^2$ where I is the object's rotational moment of inertia, and
ω is the object's rate of rotation

If the object is translating and rotating these two expressions are additive.

Airplanes and Landing Gear

When an airplane lands the weight of the aircraft is transferred from being supported by aerodynamic lift to being supported by the landing gear. For an airplane descending towards the ground at a constant rate, the landing gear must also supply the force to decelerate the aircraft to a zero vertical velocity. This force is not constant over the time the aircraft is decelerating however, so it is more convenient and common to refer to this "force" requirement in energy terms, i.e. how much "work" that must be done by the gear, or its "energy absorption" requirements. For an airplane which is already decelerating prior to touchdown (i.e. the total lift exceeds the weight of the aircraft) the required gear energy absorption is less since some of the "work" to slow the airplane's descent is being done by lift. Conversely, if the airplane is accelerating (downward) prior to touchdown (i.e. the total lift is less than the weight of the aircraft) the required gear energy absorption is greater. These phenomena can be quantified as follows:

Just prior to touchdown the airplane's energy state (with regard to vertical motion) can be computed by totaling the instantaneous kinetic and gravitational potential energies:

$$E_0 = Mgh_0 + \tfrac{1}{2}Mv_0^2 + \tfrac{1}{2}I\omega_0^2$$

Where h_0,v_0, and ω_0 are the height of the airplane's center of mass, *the instantaneous vertical velocity (sink rate), and the instantaneous roll rate just prior to touchdown. Note that the instantaneous yaw and pitch rates are assumed to be small and negligible.*

Similarly, the airplane's energy state (with regard to vertical motion) after the aircraft has decelerated to zero vertical velocity and zero roll rate can be computed as:

$$E_1 = Mgh_1 + \tfrac{1}{2}Mv_1^2 + \tfrac{1}{2}I\omega_1^2$$

Where h_1 is the height of the airplane's center of mass at the moment the aircraft ceases to sink and roll, and v_1, and ω_1 are zero. Note again that the instantaneous yaw and pitch rates are assumed to be small and negligible.

Since the vertical velocity and roll rate are zero, this reduces to:

$$E_1 = Mgh_1$$

From the "before and after" energy states we can compute the change in energy:

$$\Delta E = E_0 - E_1 = Mgh_0 + \tfrac{1}{2}Mv_0^2 + \tfrac{1}{2}I\omega_0^2 - Mgh_1$$

This expression can be further simplified to:

$$\Delta E = Mg(h_0 - h_1) + \tfrac{1}{2}Mv_0^2 + \tfrac{1}{2}I\omega_0^2$$

Since energy must be conserved, this difference must be accounted for. During the airplane's deceleration there are two possible sources for vertical forces. The first source is aerodynamic lift; the second is landing gear. If we can assume that the aerodynamic lift remains relatively constant during the time that the aircraft is being decelerated we can calculate the work done by lift as:

$$W_L = L(h_0 - h_1)$$

Where L is the total aerodynamic lift

The work that must be performed by the landing gear (i.e. the energy that must be absorbed by the gear) is then:

$$W_G = \Delta E - L(h_0 - h_1)$$

If the total aerodynamic lift is expressed as a ratio of the airplane's weight this expression becomes:

$W_G = \Delta E - R_L W(h_0 - h_1)$ where $R_L = 1.0$ if lift equals weight
$R_L = 1.1$ if lift equals 110% weight
$R_L = 0.9$ if lift equals 90% weight
etc.

And since the weight of the aircraft equals its mass times the acceleration of gravity:

$$W_G = \Delta E - R_L Mg(h_0 - h_1)$$

This expression can be expanded to:

$$W_G = Mg(h_0 - h_1) + ½Mv_0^2 + ½I\omega_0^2 - R_L Mg(h_0 - h_1), \text{ or}$$

$$W_G = Mg(1 - R_L)(h_0 - h_1) + ½Mv_0^2 + ½I\omega_0^2$$

This can also be expressed as follows:

$W_G = Mg(1 - R_L)(h_0 - h_1) + \mathbf{K}$, where **K** is the total kinetic energy at touchdown

From this expression the following conclusions can be drawn:

- If $R_L = 1.0$ (lift equals weight) the landing gear must absorb the airplane's kinetic energy as measured just prior to touchdown
- If $R_L = 1.1$ (lift equals 110% weight) the landing gear's work is reduced by *10% of the gravitational potential energy "released" as the aircraft sinks from h_0 to h_1.*
- If $R_L = 0.9$ (lift equals 90% weight) the landing gear's work is increased by 10% of the gravitational potential energy "released" as the aircraft sinks from h_0 to h_1.

And finally, for the case we are interested in for the FedEx accident investigation:

If $R_L = 0.5$ (lift equals 50% weight) the landing gear's work is increased by 50% of the gravitational potential energy "released" as the aircraft sinks from h_0 to h_1.

How do I figure out what (h_0 - h_1) is?

This distance (h_0 - h_1) is the distance over which the aircraft center of mass moves as the airplane is decelerated to zero vertical speed and zero roll rate. For the ideal case (symmetric landing on the two main landing gear with no roll rate) this distance is simply the length change (stroke) of the gear as the aircraft is decelerated (again assuming that the aircraft pitch change is small during the time the gear is stroking). For the rolled landing (h_0 - h_1) is more difficult to determine. If the combination of sink rate, roll attitude, and roll rate are such that both main gear "work" (but one more than the other), (h_0 - h_1) could be approximated by averaging the "travel" of the two main gear (where the "travel" of the gear-that-hit-first is simply its stroke, and the "travel" of the gear-that-hit-second is its stroke added to the distance it was off the ground when the other gear first touched down). For the case where the sink and roll is completely arrested by one main gear (and then the aircraft "bounces" and rolls back onto the other main), (h_0 - h_1) would be the stroke of the initially loaded gear.

5.10 Main Landing Gear Energy Analysis

RMLG Energy - Newark MD-11 Accident

- **RMLG Energy During Accident:**
  - **Potential Energy Due to Reduced Lift = 678,000 ft.-lb. = (452000)(0.5)(3)**
  - **Kinetic Energy = <u>895,754 ft. lb.</u>**
  - **Total Energy = *1,574,000 ft.-lb.***
    - **452,000 lb. Landing Weight**
    - **11 fps Sink Rate @ c.g. and 7°/sec roll rate**
    - **Lift = 0.5 X Weight**
    - **MLG Strut Stroke = 23 in.**
    - **MLG Tire Deflection = 13 in.**
- **RMLG Energy for Certification = <u>494,500 ft.-lb.</u> = $(0.5)[(491500)(.45)\div 32.2](12)^2$**
  - **491,500 lb. Max. Certified Landing Weight (45% of this is the effective weight on one wing-mounted MLG); symmetrical landing**
  - **12 fps Sink Rate (FAR 25.723 Reserve Energy Condition)**
  - **Lift = Weight (FAR 25.473)**
- **RMLG Energy During Accident Relative to Energy for Certification: (1,574,000/494500)x100 % = *<u>318 %</u>***

RMLG Energy - Faro DC-10-30 Accident

- **RMLG Energy During Accident:**
  - **Potential Energy Due to Increased Lift = -106,000 ft.-lb.**
  - **Kinetic Energy = 1,259,300 ft. lb.**
  - **Total Energy = *1,153,300 ft.-lb.***
    - **353,000 lb. Landing Weight**
    - **15 fps Sink Rate @ c.g. and 6°/sec roll rate**
    - **Lift = 1.1 X Weight**
    - **MLG Strut Stroke = 23 in.**
    - **MLG Tire Deflection = 13 in.**
- **RMLG Energy for Certification = 438,700 ft.-lb.**
  - **436,000 lb. Landing Weight, symmetrical landing**
  - **12 fps Sink Rate (FAR 25.723 Reserve Energy Condition)**
  - **Lift = Weight (FAR 25.473)**
- **RMLG Energy During Accident Relative to Energy for Certification: (1,153,400/438,700) x 100 % = *263 %***

RMLG Energy--TWA L-1011 (JFK)

- **RMLG Energy During Accident:**
  - **Potential Energy Due to Reduced Lift = 268,108 ft.-lb.**
  - **Kinetic Energy = <u>1,305,556 ft.-lb.</u>**
  - **Total Energy = 1,573,664 ft.-lb.**
  - **Factor for 1.1° RWD LG Load Distrib. LMLG 45%, RMLG 55%**
  - **RMLG saw 1,573,664 ft.-lb. X 0.55 = 865,515 ft.-lb.**
    - **428,973 lb. Takeoff Weight**
    - **14 fps Sink Rate**
    - **Lift = 0.75 X Weight**
    - **MLG Strut Stroke and MLG Tire Deflection = 2.5 ft (estimated)**
- **RMLG Energy for Certification = 400,248 ft.-lb.**
  - **358,000 lb. Max. Certified Landing Weight, Symmetrical Landing**
  - **12 fps Sink Rate (FAR 25.473)**
  - **Lift = Weight (FAR 25.473)**
- **RMLG Energy During Accident Relative to Energy for Certification:**

  (865,515/400,248) X 100 = *<u>216%</u>*

5.11 ADAMS Illustrations

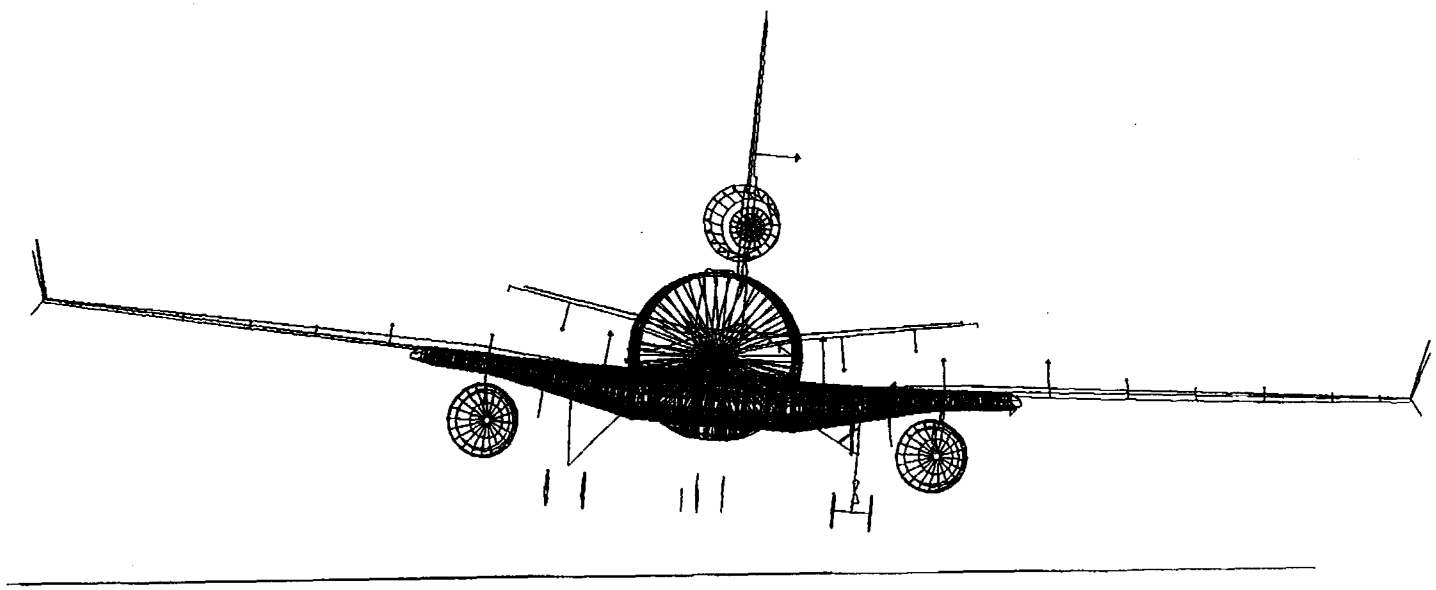


Figure 1

Just Prior to 2nd Touchdown Impact

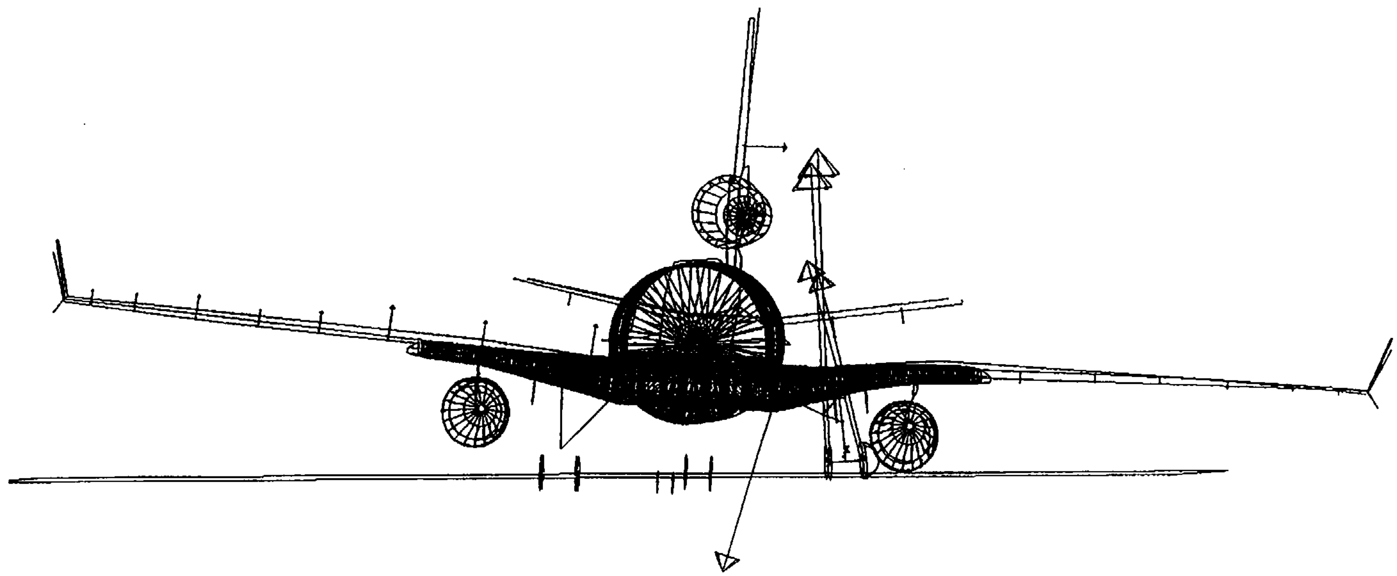


Figure 2

Second touchdown impact. Rear-spar-web-failed idealization. RMLG strut and tires bottomed in this view.. Lift on right wing outboard of landing gear reduced due to wing-leading-edge-down twist. Note the diminished (actually reversed) right wing lift vectors. The large upward-pointing vectors are generated by forces acting upon the inboard and outboard RMLG tires. The downward-pointing vector is generated by forces acting upon the trap-panel-to-side-brace-fitting joint.

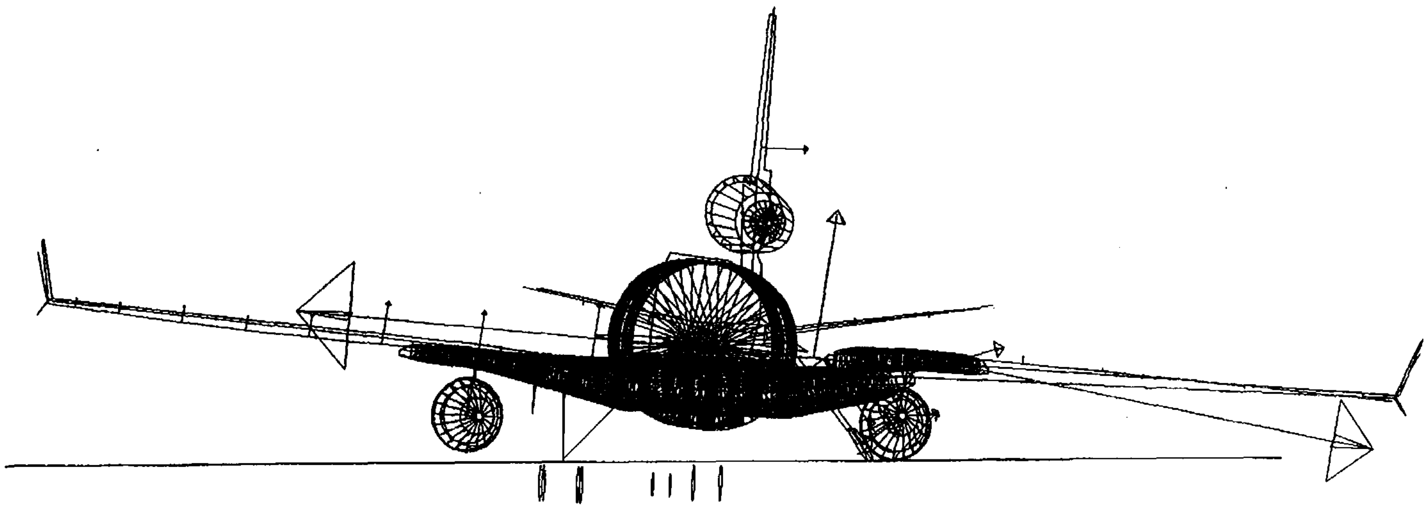


Figure 3

After second touchdown impact. Entire-wing-cross-section-failed idealization.