NATIONAL TRANSPORTATION SAFETY BOARD
Office of Aviation Safety
Washington, D.C. 20594

STRUCTURES GROUP CHAIRMAN'S FACTUAL REPORT

December 12, 2019

A. ACCIDENT: DCA19FA143

Operator:	Miami Air International flight 293
Location:	Jacksonville, Florida
Date:	May 3, 2019
Time:	2142 Eastern Daylight Time
Aircraft:	Boeing 737-81Q
Registration:	N732MA

B. STRUCTURES GROUP

Chairman:	Clinton R. Crookshanks National Transportation Safety Board Denver, Colorado
Member:	William (Rusty) Browning The Boeing Company Everett, Washington
Member:	Mark Easton Miami Air International Miami, Florida

C. SUMMARY

On May 3, 2019, at 2142 eastern daylight time, Miami Air International flight 293, a Boeing 737-81Q, registration N732MA, was landing on runway 10 at Jacksonville Naval Air Station, Jacksonville, Florida, when it departed the end of the runway, contacted a stone embankment, and came to rest in shallow water in the St. Johns River. The 2 pilots, 4 flight attendants, 1 mechanic, and 136 passengers were not seriously injured. The airplane was substantially damaged. Flight 293 was a non-scheduled passenger flight from Leeward Point Field, Naval Station Guantanamo Bay, Cuba, operating under the provisions of 14 Code of Federal Regulations Part 121 Supplemental.

Instrument meteorological conditions prevailed at the time of the accident, and rain was occurring during the landing.

D. DETAILS OF THE INVESTIGATION

1.0 Airplane Overview

The Boeing 737-81Q airplane is a twin-engine, narrow-body, transport category airplane (Figure 1[1]) equipped with two CFM56-7 turbofan engines, a conventional tail, and retractable tricycle landing gear. The airplane is 129 feet, 6 inches long, 41 feet, 2 inches tall at the tail, has a wingspan of 117 feet, 5 inches, and has a horizontal stabilizer span of 47 feet, 1 inch. The airplane primary structure is of all metal construction, primarily aluminum alloys. The elevators, rudder, ailerons, and winglets are of composite construction along with many of the fairings, doors and panels. The accident airplane was manufactured in 2001with S/N 30618.

Boeing defines the location of parts of the airplane longitudinally and laterally using station and buttock locations and vertically using waterline locations measured in inches from a datum as shown in Figures 2 and 3. The fuselage station (STA) datum is located 130 inches forward of the nose of the airplane. The 737-800 has an extended fuselage as compared to the original 737 fuselage. The forward fuselage extension is installed between STA 500 and STA 520 with the fuselage plug stations designated as STA 500A through STA 500I in this area. The aft fuselage extension is installed between STA 727 and STA 747 with the fuselage plug stations designated as STA 727A through STA 727J in this area. The identified fuselage stations on the diagram define the frame locations and are nominally 20 or 22 inches apart. In the fuselage plug sections, measurements are in the format STA 500A+XX where XX is the measurement in inches aft of the plug station location. Longitudinal stringers are installed on the interior side of the fuselage skin with stringer (S) 1 at the upper centerline of the airplane. The left side stringers are designated S-2L to S-28L in section 43 and S-2L to S-27L in section 46. The right side stringers are designated S-2R to S-28R in section 43 and S-2R to S-27R in section 46. There is no stringer located at the lower centerline of the airplane. The passenger windows are installed between the S-11 and S-13 locations on each side. The wing station (WS) datum is located at the centerline of the airplane at wing buttock line (WBL) 0 and distances on the left and right sides are measured outboard to the end of the wing. WS locations are measured along planes perpendicular to the wing forward spar and WBL locations are measured along planes parallel to the longitudinal axis of the airplane. The waterline (WL) datum is parallel to the ground and located 148.5 inches below the lower centerline of the airplane.

2.0 Accident Site

The airplane exited the end of runway 10 to the right of the runway centerline and traveled through the grass on the south side of the paved blast pad. There were distinct tire marks through the grass from both main landing gear (MLG) and the nose landing gear (NLG). The NLG tire marks in the grass were midway between the MLG tire marks at the end of runway 10 and transitioned to being coincident with the RMLG tire marks by the end of the grass area. The airplane impacted a rock embankment at the end of the runway 10 overrun area before coming to rest in the shallow water

[1] All figures are presented in Appendix A.

of the St. Johns River. The water was 3-5 feet deep depending on the tidal conditions. There were distinct areas of disturbed rocks on the embankment consistent with the locations of the engines and main landing gear based on the tire marks in the grass leading up to the embankment. The airplane was mostly intact but damaged. The center of the airplane was about 100 feet east of the rock embankment that defined the edge of the river and about 75 feet south of the landing light pier (Figure 4). The landing light pier was located along the extended centerline of the runway and was not frangible in its design. The airplane location was about 1300 feet east of the runway 10 edge and 350 feet east of the runway 28 blast pad edge. The heading of the airplane was estimated to be 115° true based on photos and Google Earth. Portions of the engine cowlings, the radome, and both main landing gear separated during the accident sequence and were located in the water adjacent to the airplane or on the rock embankment. Three life rafts were recovered in the water around the airplane. The L1 and R1 (forward) doors and the 4 overwing emergency exits were open. The L2 and R2 (aft) doors were closed. The L1 door evacuation slide was inflated and partially attached to the door sill and the R1 door evacuation slide was hanging from the door sill uninflated. The flight data recorder (FDR) and emergency locator transmitter (ELT) were recovered from the airplane on May 3.

3.0 Recovery

Lone Star Retrieval (LSR) was contracted by the airline's insurance company to recover the wreckage. The remains of three pets that were killed in the accident were recovered from the forward cargo compartment on May 5 and turned over to the Navy veterinarian. Limited examination of the airplane occurred while the airplane was in the water. The airplane was defueled through the refueling adaptor on the right wing using a vacuum truck on May 5-6. About 1400 gallons of fuel were removed from the airplane.

The separated MLG, radome, and engine cowling pieces were recovered from the water first. The LMLG was recovered about 30 feet aft of the left wing and the RMLG was recovered about 30 feet forward of the right wing. The upper inboard fixed trailing edge panels were removed over the main landing gear bays to access the MLG beams. Lift straps were placed around the MLG beams to carry most of the weight of the airplane during the lift. Another strap was placed around the forward fuselage about STA 360 for the lift. The plane was lifted from the water (Figure 5) and placed on a barge for transport on May 7. The crane lifting at the MLG beams registered 97,000 pounds and the crane lifting at the forward fuselage registered 15,000 pounds during the lift. The airplane was held above the surface to drain the water in the lower fuselage prior to being placed on the transport barge. The cockpit voice recorder (CVR) was recovered from the aft cargo compartment of the airplane on May 7 after the airplane was placed on the barge. The airplane was transported about 17 miles upriver to Green Cove Springs, Florida, and placed in an open field at Reynolds Park Marina for examination by the investigative groups. The luggage was removed from the forward and aft cargo compartments and turned over to BMS CAT prior to lifting the airplane from the barge to the field. The second lift was performed at the same points. The crane lifting at the MLG beams registered 89,000 pounds and the crane lifting at the forward fuselage registered 10,000 pounds during the lift. The airplane was placed on cribbing and secured with straps before examination.

Prior to examining the airplane, the potentially hazardous equipment was made safe. The oxygen generators in the cabin were all activated and allowed to vent. The pressurized oxygen bottles in the cockpit, cabin, lavatories, and the personal breathing equipment masks were depressurized. The engine and APU fire handles were pulled and turned after the accident and the remaining intact squibs on the engine, APU, and cargo fire bottles were removed and turned over to the Jacksonville Sherriff's office for destruction. The food in the galley carts was removed and thrown away. The MLG tires were measured and depressurized after they were recovered from the water. The NLG tires were punctured during the accident.

The airplane was examined by the investigative groups May 9-12. The airplane wreckage was fenced, and a private security company was used to secure the wreckage during the examination and for the weeks following the accident.

The airplane was partially dismantled and transported to a secure storage facility August 7-21, 2019. Where possible, items were disconnected and removed per existing procedures in the Aircraft Maintenance Manual (AMM). The winglets, inboard flaps, outboard flaps, Krueger flaps, and slats were disconnected from the left and right wings and removed. The ailerons were not removed from the wings. The damaged engines were disconnected from the pylons and removed. The rudder was disconnected from the vertical stabilizer and the vertical stabilizer was disconnected from the fuselage and removed. The left and right horizontal stabilizers were disconnected from the fuselage and removed with the elevators still installed. The left and right wings were removed by disconnecting the MLG beam from the hangar link and cutting the upper wing skin and stringers, lower wing skin and stringers, forward spar, and aft spar between the side-of-body rib at WBL 71.24 and the wing rib at WBL 91.24. The pylons and MLG beams were disconnected and removed from the wings after the wings were separated from the fuselage. The seats, luggage bins, interior components, floor panels, and cargo liners were removed between STA 500D and STA 500H. The fuselage was separated into two sections by cutting through the skin, stringers, and floor beams between STA 500G and STA 500F.

4.0 Wreckage Examination

The damage to the airplane was documented below. Anything not mentioned was intact and unremarkable.

4.1 Fuselage

The radome was separated from the forward pressure bulkhead at STA 178. One radome attach clip on the left side was separated and the remaining 15 clips were fractured. About 18 inches of the radome flange on the left side was fractured and separated. There was damage and fracture of the radome in the lower right quadrant. The weather radar was separated from the forward pressure bulkhead and not identified in the recovered wreckage. The 4 weather radar mounts were fractured. There was denting of the lower fuselage between STA 178 and STA 208 about 28 inches wide centered along BL 0 (lower centerline).

The left AOA vane was fractured from the sensor. The right AOA vane and all three pitot probes were intact and undamaged.

The NLG collapsed aft during the accident and was lodged in the lower forward fuselage. The hole in the lower fuselage skin extended 56 inches aft of the NLG wheel well and was 30 inches wide. The right edge of the hole was coincident with the electronic equipment (EE) access door hole and the left edge was coincident with stringer S-27L. The NLG trunnions were intact. The pin between the NLG and the lower drag strut was separated and not identified but the lugs were intact on both sides. The left NLG door remained attached and the right NLG door was separated. The forward half of the right NLG door was recovered in the debris field.

There was scratching and gouging, both longitudinal and angled, between STA 370 and STA 500C and between S-26L and S-26R. The angled scratches were oriented about 15° from the longitudinal axis. There were several small dents in this area. There was a hole about 12 inches wide between STA 393 and STA 418 centered near BL 0 between S-27R and S-27L. There was scratching, denting and a puncture 5 inches long and 6 inches wide between STA 418 and STA 457, from BL 0 to S-27R. There was scratching, gouging and a linear puncture between STA 477 and STA 490 near S-27R. There was a puncture spanning from STA 500E+16 to STA 500F+10 between S-24R and S-26R that was about 12 inches wide. The lower antenna between STA 460 and STA 480 was damaged.

There was major buckling damage to the section 43 fuselage forward of the wing. The damage spanned from S-6L down the left side of the fuselage and under the belly up to S-17R (Figure 6). Between S-6L and S-10L there was buckling of the skin from STA 500D to STA 520. Between S-10L and S-14L there was buckling of the skin from STA 500E to STA 500G. Between S-14L and S-24L there was buckling of the skin from STA 500F to STA 500G. There were several skin fractures coincident with the buckles in this area. Between S-24L and S-24R there was buckling of the skin from STA 500F to STA 500H. Between S-17R and S-24R there was buckling of the skin from STA 500F to STA 500G. There was minor dimpling of the fuselage skin on the right side between S-14R and S-21R from STA 500C to STA 500F. The outer pane of the left passenger window between STA 500H and STA 500I was separated and not identified in the recovered wreckage. The outer pane of the left passenger window between STA 520 and STA 540 was dislodged and there was water trapped between the outer and inner panes. There was water trapped between the outer and inner panes of the left passenger window between STA 559 and STA 578. The internal fuselage frames and stringers were buckled coincident with the skin buckling in this area.

There was a hole and damage on the upper fuselage skin above the right forward overwing emergency exit (Figure 7). There was an area of black rubber transfer about 4 inches wide between STA 529 and STA 540 at the S-14R location. There was scratching, gouging, and denting of the fuselage skin between STA 500I+9 and STA 539 from S-10R to S-11R. There was a gouge and a puncture between STA 542 and STA 552 from S-9R to S-10R. There was an area of scuffing, black rubber transfer marks, and gouging between STA 586 and STA 614 from S-7R to S-10R. There was an area of scratching and denting between STA 610 and STA 619 from S-4R to S-5R. There was scratching, gouging, denting, and blue paint transfer between STA 622 and STA 649 from S-9R to S-10R. There was scuffing and gouging between STA 664 and STA 677 from S-9R to S-10R. There was an area of black rubber transfer between STA 673 and STA 677 about 2 inches wide at the S-15R location. The hole spanned from STA 559 to STA 597 and was between S-6R and S-8R. There was scuffing of the paint at the aft end of the hole. A piece of blue wiring

about 10 inches long with a pin attached at one end was lodged in the deformed fuselage skin. The wire was retained for analysis. There was blue grease splattered on the back side of the overhead bin and on the upper surface of the passenger service unit (PSU) structure inside the hole above seat rows 12DEF and 14DEF (Figure 8). Blue grease was visible from inside the airplane between the edges of the PSU panels. A sample of the grease was retained for analysis. The overhead bin was cracked on the outboard side.

The right and left retractable landing lights in the wing-to-body (WTB) fairing near STA 530 were separated and not identified in the recovered wreckage. The antenna located at BL 0 between STA 500E and STA 500F was fractured and separated. There was scratching, gouging and denting in the skin aft of the antenna. The drain mast located at BL 0 centered at STA 525 was damaged.

The left lower forward WTB fairing panel was fractured in multiple places. The left environmental control system (ECS) bay access panel forward of the left wheel well was separated and not identified in the recovered wreckage. The panel attach fasteners remained intact and engaged. The lower portion of the left WTB fairing around the left wheel well was fractured in multiple places. The lower portion of the right WTB fairing around the right wheel well was fractured and damaged. The WTB fairing panel aft of the left wheel well was fractured in multiple places. The WTB fairing center panel between the wheel wells had a hole about 17 inches by 7 inches at the aft end and the attach flange was deformed aft. The lower center aft WTB fairing panel aft of the wheel wells was separated and not identified in the recovered wreckage. All the panel attach fasteners were intact and engaged. The lower beacon light lens was broken.

The right WTB fairing was punctured and scratched above the inboard end of the right inboard flap. The scratching was circular between STA 727A+3 and STA 727B+10. There was a triangular shaped puncture in the right WTB fairing about STA 727A+5 and another puncture about STA 727A+8. There were 2 areas of black rubber transfer on the right WTB fairing, one was 2.5 inches by 4 inches and centered about STA 727B+12, the other was 2.5 inches by 3 inches and centered about STA 727C+2.

There was an area of damage and black rubber transfer marks on the left WTB fairing aft of the left wing between STA 727B and STA 727D. There was a black rubber transfer mark adjacent to the inboard end of the left inboard flap about 5 inches tall between STA 727B and STA 727B+5. There was an area of circular scratching, gouging, and black rubber transfer about 14 inches tall between STA 727B+11 and STA 727C+3. There was an area of scratching and black rubber transfer about 26 inches tall between STA 727C+18 and STA 727D. The black rubber transfer marks continued onto the fuselage skin between S-17L and S-18L.

There was gouging and a small dent from STA 727E+14 to STA 727F at S-23R. There was an area of scratching, gouging, denting and skin punctures located between STA 783 and STA 887 and between S-23L and S-25L. The lavatory access panel was damaged and fractured from the hinges. It remained attached to the fuselage by the ground strap. There was a small puncture about 3 inches wide from STA 809 to STA 815 near S-24L. There was a small puncture about 2 inches long by 1 inch wide at the lower aft corner of the lavatory access panel. There was an area of scratching, gouging, and denting located between STA 847 and STA 920 and from S-21L to S-24L. There was an area of linear, parallel scratches oriented about 15° from the longitudinal axis

that spanned from STA 727H to STA 1005 between S-25L and S-25R. The scratching was concentrated at the frame and stringer locations with little or no scratching in the frame bays. There were no punctures of the skin in this area. The hydraulic drain mast between STA 727B and STA 727C was damaged and the antenna at BL 0 between STA 727F and STA 727G was separated.

The tail skid remained attached and was undamaged.

4.2 Empennage

The horizontal stabilizer, vertical stabilizer, elevators and rudder were intact and undamaged.

4.3 Wings

The wings were intact and mostly undamaged. The slats and flaps were intact and undamaged except where noted below. The flaps and slats were in an extended position. The winglets were intact and undamaged. The pylon fuse pins were all visually examined and appeared intact.

4.3.1 Left Wing

Spoiler No.4 on the left wing was separated and the inboard portion of Spoiler No.3 was crushed and deformed. Portions of Spoiler No.4 were recovered with impact damage and deformation. The leading edge of the left outboard main flap was crushed downward beneath the Spoiler No.3 and No.4 locations. There was linear scratching and gouging on the upper surface of the left outboard main and aft flaps aft of the Spoiler No.4 location. There was scratching, gouging, and crushing on the upper portion of Slat No.1 on the left wing. The 3rd vortex generator from the outboard end of the left wing was separated. There was a gouge on the 4th fuel tank access door outboard of the pylon.

The left outboard aft flap had crushing and gouging damage on the leading edge and the inboard program roller was disengaged from its track. The left inboard main flap had crushing damage and blue paint transfer on the lower surface. The trailing edge of the main flap was fractured. The left inboard aft flap remained attached to the main flap by the push rods. The inboard push rod was bent upward and the outboard push rod was not deformed. The program rollers on the left inboard aft flap were disengaged from their tracks on the main flap. There was no deformation of the program roller fittings on the left inboard aft flap. The inboard and outboard aft flap track mounts were fractured.

The left forward trunnion bearing housing (H-block) shear pin heads, 4 in total, remained in place in the H-block fitting. The lower stabilizing link aft fitting was fractured but the link remained attached at the forward end. The lower stabilizing link forward fuse pin was intact. The lower stabilizing link aft fuse pin was fractured but remained installed. The doghouse attach fitting was fractured through the lug. The left aft trunnion bearing was rotated down and inboard in its housing. There was impact damage to the lower flange of the MLG beam below the aft trunnion. The MLG beam hanger link was partially fractured at the forward frame attach point. There were no fractures of the rear spar and no evidence of fuel leakage. The left outboard MLG beam support fuse pin exhibited slight crankshaft deformation upon removal but was able to be driven out.

The left pylon was disconnected from the wing by removing the fuse pins. The pins in the upper link (R1), diagonal brace (R2), outboard aft upper spar fitting (R3), outboard side link (R7), and

inboard side link (R8) pushed out easily after removing the bolts. The left inboard aft upper spar fitting (R4) pin would not push out. Several relief cuts were made in the pin and the inboard R4 clevis lug was cut away in order to remove the pin. The R4 fuse pin exhibited crankshaft deformation (Figure 9).

4.3.2 Right Wing

The trailing edge of Spoiler No.7 on the right wing had a semi-circular area of damage that included black rubber and blue paint transfer. There was a black rubber transfer mark about 7 inches long by 17 inches wide on the right upper fixed trailing edge panels in the non-skid area. The lower fixed trailing edge panels aft of the right wheel well were fractured.

There was upward crushing, blue paint transfer, and gouging on the underside of the right inboard main flap. The main flap was buckled upward, and a section of the trailing edge was separated. The right inboard aft flap remained attached to the main flap by the push rods, but the push rods were bent upward. There was tearing damage in the upper skin of the main flap coincident with the push rod locations. The program rollers on the right inboard aft flap were disengaged from their tracks on the main flap. The inboard and outboard aft flap track mounts were fractured. The inboard program roller fitting was fractured and deformed clockwise. The outboard program roller fitting was fractured and deformed counterclockwise. The #6 flap track hanger fitting upper outboard bolt was fractured. The carriage fitting outboard forward bolts were fractured and separated where they attach to the right inboard main flap.

The right forward trunnion H-block lower inboard shear pin head remained in place. There was a shear pin head loose on the inboard side of the H-block fitting. The outboard two shear pin heads were separated and not identified in the recovered wreckage. The lower stabilizing link aft fitting was fractured but the link remained attached at the forward end. The lower stabilizing link fuse pins were intact. The walking beam link was fractured and exhibited torsional deformation. The right aft trunnion bearing was rotated down and inboard in its housing. There was impact damage to the lower flange of the MLG beam below the aft trunnion. There were no fractures of the rear spar and no evidence of fuel leakage. The right outboard MLG beam support fuse pin was deformed and could not be driven out. The pin was cut on each side of the MLG beam in order to remove the MLG beam from the right wing.

The right pylon was disconnected from the wing by removing the fuse pins. The pins in the upper link (R1), diagonal brace (R2), inboard aft upper spar fitting (R4), outboard side link (R7), and inboard side link (R8) pushed out easily after removing the bolts. The outboard aft upper spar fitting (R3) pin would not push out. The outboard R3 clevis lug was cut away in order to remove the pin. The R3 fuse pin exhibited crankshaft deformation (Figure 10).

4.4 Engines

The engines remained attached to the pylons after the accident but suffered significant damage. The lower portions of the engine nacelles were torn and fractured, and rocks were ingested into the engines. See the Powerplant Group Chairman's Factual Report in the public docket for the details of the engine damage.

4.5 Landing Gear

See Figure 11 for a labeled drawing of the MLG and components. The right and left MLG were mostly intact and recovered adjacent to the airplane as noted above. The LMLG was intact and mostly undamaged. It was recovered in the extended position and the door remained attached. The forward trunnion was engaged in the H-block and moved freely. The H-block was separated from the H-block fitting on the rear spar and all 4 fuse pins were sheared. The tails of the fuse pins remained in the H-block. The aft trunnion was intact and mostly undamaged. There was some scuffing of the chrome on the aft trunnion. The side brace assembly was intact. The left side brace attach link was fractured and the fractured portion of the lug remained in the side brace clevis in the left wheel well. The left walking beam, retract actuator, and walking beam link were intact and undamaged.

The RMLG was intact and mostly undamaged. It was recovered in the extended position and the upper portion of the door remained attached. The lower portion of the door was separated and recovered. The forward trunnion was engaged in the H-block and moved freely. The H-block was separated from the forward trunnion fitting on the rear spar and all 4 fuse pins were sheared. The tails of the fuse pins remained in the H-block. The aft trunnion was intact and mostly undamaged. There was some scuffing of the chrome on the trunnion. The side brace assembly was intact. The right side brace attach link was fractured and the fractured portion of the lug remained in the side brace clevis in the right wheel well. The right walking beam link was fractured and exhibited torsional deformation. The walking beam and retract actuator were intact and undamaged. A sample of grease from the RMLG was retained for analysis. A wire bundle containing red, yellow, and blue wires was cut from the RMLG and retained for analysis. The red and yellow wires were intact to the ends and the blue wire was separated about 10 inches from the ends of the red and yellow wires. The pin was separated from the red wire.

5.0 Tests and Research

5.1 MLG Breakaway

Boeing has designed the MLG and support structure for the anticipated landing and taxi loads expected in service. In addition, special consideration has been given to loads generated during an abnormal landing such that the MLG will break away from the airplane during an overload event without causing a breach of the wing fuel tanks in accordance with the pertinent FAA regulations. The MLG forward trunnion is attached to the H-block that is fastened to the wing rear spar. The wing rear spar serves as the aft wall of the wing fuel tank. The design overloads are assumed to act in the upward and aft directions as required by the regulations and Boeing has considered side overloads as well. The MLG design incorporates several fuse locations that will break away at known overload levels and in a certain sequence. Each fuse location incorporates hollow fuse pins that will fail at load levels less than the surrounding structure. There are 4 fuse pins used to attach the forward trunnion H-block to the fitting on the wing rear spar, a single fuse pin on each of the upper and lower stabilizing links, and a single fuse pin to attach the outboard end of the MLG beam to the dog house fitting. The Boeing analysis for a drag overload event similar to the accident event allows for the H-block to separate from the rear spar fitting in a downward direction failing all 4 fuse pins. The landing gear assembly will then rotate aft, pivoting about the aft trunnion bearing in the MLG beam. The walking beam and actuator will impact the lower stabilizing link failing the fuse pin. The MLG will then slide out of the aft trunnion bearing. At some point in the

sequence, the outboard end of the walking beam must separate from the dog house fitting and the inboard end of the side brace must separate from the fitting in the wheel well allowing the MLG to separate from the airplane.

5.2 Engine Breakaway

Special consideration has also been given to loads generated during an abnormal landing such that the engines and/or pylons will break away during an overload event without causing a breach of the wing fuel tanks. The Boeing analysis examined the loads on the pylons at 0° and 20° of yaw with the nacelles intact and any combination of landing gear retracted. The critical interface becomes the pylon to wing attachments where fuse pins are installed. A single fuse pin is installed at the upper link (R1), diagonal brace (R2), outboard aft upper spar fitting (R3), inboard aft upper spar fitting (R4), outboard side link (R7), and inboard side link (R8) connection points to the wing. Depending on the specific loading conditions the fuse pins will fail in a sequence that allows the engine and pylon to separate up and over the wing without causing fuel tank damage.

5.3 Material Testing

Portions of a three-wire harness from the RMLG and a section of wire found captured in the damaged skin above the right overwing emergency exit were examined under group supervision at the Boeing Equipment Quality Analysis (EQA) lab. See Appendix B to this report for the EQA report. The RMLG wire harness contained a red, yellow, and blue wire all cut at the same location. The red and yellow wires were intact to their terminus, but the pin connector was missing from the red wire. The red and yellow wires measured between 26.5 and 27.5 inches in length. The blue wire was fractured about 17 inches from the cut end. The section of blue wire from the fuselage was fractured at one end with a pin connector at the opposite end and measured about 10 inches long. The fractured ends of the blue wire sections were examined under a microscope. Both fractured ends exhibited necking of the individual wire strands and cup and cone fracture features on the strands consistent with tension overload failure. The section of wire from the fuselage had two wire strands that were noticeably longer than the others and the section of wire from the RMLG had two wire strands that were noticeably shorter than the others. The difference in length between the shorter and longer strands was consistent between the two wire sections.

Two grease samples taken from the accident airplane were also examined at the EQA lab. One sample was retrieved from the back side of the luggage bins inside the fuselage hole above the right overwing emergency exit and the second sample was retrieved from the RMLG. Chemical analysis of both grease samples showed that they were very similar to each other in overall chemistry and were consistent with the grease used to lubricate the MLG during maintenance at Miami Air (BMS3-33).

5.4 FAA Regulations

The Boeing 737-800 was approved by the FAA on March 13, 1998, as detailed in type certificate data sheet A16WE with a certification basis at 14 *Code of Federal Regulations* (14 CFR) Part 25, Amendment 25-77 (with exceptions). Two specific rules deal with the fuel tank and landing gear structural requirements, 25.721 and 25.963. At the time of certification, the regulations were as follows.

25.721 Landing Gear: General. (effective May 1, 1972 at Amendment 25-32)
(a) The main landing gear system must be designed so that if it fails due to overloads during takeoff and landing (assuming the overloads to act in the upward and aft directions), the failure mode is not likely to cause -

(1) For airplanes that have passenger seating configuration, excluding pilots seats, of nine seats or less, the spillage of enough fuel from any fuel system in the fuselage to constitute a fire hazard; and

(2) For airplanes that have a passenger seating configuration, excluding pilots seats, of 10 seats or more, the spillage of enough fuel from any part of the fuel system to constitute a fire hazard.

(b) Each airplane that has a passenger seating configuration excluding pilots seats, of 10 seats or more must be designed so that with the airplane under control it can be landed on a paved runway with any one or more landing gear legs not extended without sustaining a structural component failure that is likely to cause the spillage of enough fuel to constitute a fire hazard.
(c) Compliance with the provisions of this section may be shown by analysis or tests, or both.

25.963 Fuel tanks: General. (effective October 30, 1989, Amendment 25-69)
(a) Each fuel tank must be able to withstand, without failure, the vibration, inertia, fluid, and structural loads that it may be subjected to in operation.
(b) Flexible fuel tank liners must be approved or must be shown to be suitable for the particular application.
(c) Integral fuel tanks must have facilities for interior inspection and repair.
(d) Fuel tanks within the fuselage contour must be able to resist rupture and to retain fuel, under the inertia forces prescribed for the emergency landing conditions in 25.561. In addition, these tanks must be in a protected position so that exposure of the tanks to scraping action with the ground is unlikely.
(e) Fuel tank access covers must comply with the following criteria in order to avoid loss of hazardous quantities of fuel:

(1) All covers located in an area where experience or analysis indicates a strike is likely must be shown by analysis or tests to minimize penetration and deformation by tire fragments, low energy engine debris, or other likely debris.

(2) All covers must be fire resistant as defined in part 1 of this chapter.

(f) For pressurized fuel tanks, a means with fail-safe features must be provided to prevent the buildup of an excessive pressure difference between the inside and the outside of the tank.

Both regulations were revised to eliminate differences between the airworthiness standards of the FAA and the European Aviation Safety Agency (EASA) after a harmonization effort and became effective December 1, 2014. The revisions did not add additional requirements to the FAA regulations beyond what was already required under EASA regulations or beyond the current industry design practices. The landing gear regulation (25.721) revision expanded the failure conditions to include side loads in addition to the up and aft loads, added the NLG to the requirements, specified a descent rate for the wheels-up landing condition, added a sliding on ground condition, and required the engine mount to be designed such that failure would not cause a fuel spillage hazard. The fuel tank regulation (25.963) revision required that fuel tanks be designed so that a fire hazard wouldn't exist in survivable emergency landing conditions, defined fuel tank pressure loads, and specified the wheels-up landing conditions and landing gear and engine mount failure conditions that must be considered.