Aviation Investigation Final Report

Location:	Miami, Florida	**Accident Number:**	DCA22FA132
Date & Time:	June 21, 2022, 21:38 UTC	**Registration:**	HI-1064
Aircraft:	McDonnell Douglas MD80	**Aircraft Damage:**	Substantial
Defining Event:	Landing gear collapse	**Injuries:**	4 Minor, 136 None
Flight Conducted Under:	Part 129: Foreign		

Analysis

The collapse of the left main landing gear during the landing roll resulted in a runway excursion due to a loss of controllability on the runway, during which the aircraft impacted a small equipment building, breaching the right-wing fuel tank and causing a post-crash fire. The performance of the crew was thoroughly evaluated during this investigation and found to be appropriate for the circumstances of the accident.

The focus of this analysis is the cause of the left main landing gear collapse. Particularly (1) the left shimmy damper's failure to adequately dampen vibration during landing and (2) the failure of the left main gear downlock mechanism due to excessive vibration. Figure 1 is a representation of how vibrations are typically dampened by a fully functioning shimmy damper. Figure 2 shows the rubber tire transfer markings that indicate the left main landing gear was shimmying down the runway.

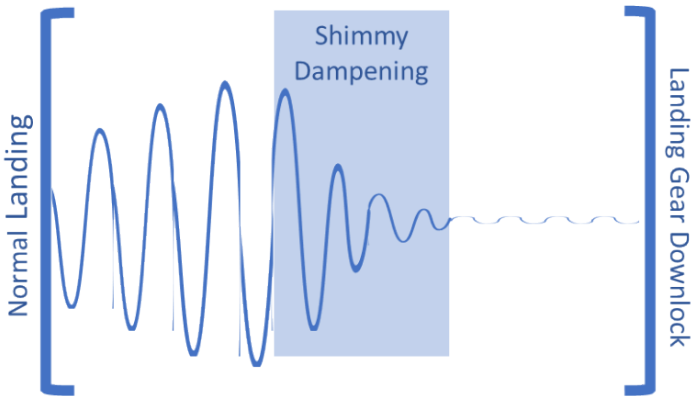

Figure 1. The blue line is a representation of vibrations from a normal landing dampened by normally operating shimmy dampers when both main landing gear are down and locked. Note: Figure is not to scale nor depicting actual data.

Figure 2. Photos showing the left landing main landing gear tire transfer marks indicating shimming of the landing gear.

Left Shimmy Damper Failure

The left shimmy damper was examined and found to be assembled correctly. However, the check valve was found to be leaking and the cap for the check valve service port was missing. The damper requires sufficient hydraulic fluid to adequately dampen normal vibrations in the

system. For a significant amount of fluid to leave the damper, there would have to be failure of both the check valve and the cap for the service port.

If the leak in the check valve existed prior to the accident flight, there was potential for it to be discovered by maintenance when servicing the shimmy damper with hydraulic fluid. When a damper is serviced, documentation of that service must be made in the maintenance logs. The investigation's review of maintenance logs revealed that the last time the left shimmy damper was serviced was in June of 2021, 12 months prior to the accident.

Damage to check valves typically occur during servicing and any leaks would occur following a servicing event. Considering the last documented servicing of the shimmy damper occurred 1 year prior to the accident, it is likely that the check valve leak had silently developed and was sitting latent until a problem with the service port cap occurred.

The shimmy damper was checked the day before the accident per the "S" check. There was no record of the damper being serviced during this "S" check suggesting that the service port cap was present and hydraulic fluid levels were above minimums. Therefore, the investigation deduced that the cap went missing or was compromised at some point in the 2 flights and 24 hours between the last "S" check and the accident touchdown. After the service port cap failed, sufficient fluid likely leaked from the damper through the leaking check valve and the uncovered service port in the hours prior to the accident, ultimately compromising the functionality of the shimmy damper.

Unfortunately, the physical breach of the reservoir inflicted during the gear collapse resulted in the release of hydraulic fluid and precluded evaluation of whether the damper was properly serviced. This limited the investigation's ability to definitively determine the root causes behind the apparent check valve and service port cap failure. The investigation explored potential contributions of operator organizational oversight and regulatory oversight of operator's maintenance, however insufficient evidence existed to establish a direct link between any of these factors and the accident.

Left Main Gear Downlock Failure

Facing severe undampened axial vibration on rollout, the left main gear lower torque link (downlock) failed due to overload. When the downlock failed, the side braces were free to, and did, fold in the opposite direction from normal as the gear folded inboard and collapsed.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be:

The structural failure of the left main landing gear downlock following ineffective shimmy dampening during the landing roll which caused the collapse of the left main landing gear, resulting in a runway excursion and post-flight fire.

Findings

Aircraft	Shimmy damper - Failure

Factual Information

History of Flight

Landing-landing roll	Landing gear collapse (Defining event)
Landing-landing roll	Abnormal runway contact
Landing-landing roll	Runway excursion
Post-impact	Fire/smoke (post-impact)
Post-impact	Evacuation

On June 21, 2022, about 1738 eastern daylight time, RED Air flight 203, a Boeing MD-82, HI-1064, overran the end of runway 9 at Miami International Airport (MIA), Miami, Florida, after the left main landing gear (MLG) failed shortly after landing. The airplane impacted a concrete and steel structure in the grassy area to the left of the runway and came a stop shortly afterward. A postcrash fire ensued while the airplane was being evacuated. Of the 140 occupants aboard the airplane, 4 passengers sustained minor injuries. The postcrash fire was subsequently extinguished by aircraft rescue and firefighting (ARFF) personnel from Miami-Dade Fire Rescue. The airplane was operating under Title 14 *Code of Federal Regulations* Part 129 as a scheduled international passenger flight from Las Américas International Airport (SDQ), Santo Domingo, Dominican Republic, to MIA.

The flight crew arrived at MIA about 0830 for the first flight of the day, from MIA to SDQ. The first officer conducted a walkaround of the airplane and observed no anomalies. The airplane departed MIA about 1028 and arrived at SDQ about 1115. The accident flight departed SDQ about 1435. The captain was the pilot monitoring, and the first officer was the pilot flying.

The takeoff, climb, and en route phases of flight were uneventful. The flight was cleared for the instrument landing system approach to runway 9, and the flight crew stated that the approach was normal. The first officer disconnected the autopilot when the airplane was descending from 400 to 200 ft above ground level and then manually flew the airplane for the remainder of the flight.

The first officer recalled that the airplane touched down smoothly on the right and then the left MLG and that the airplane was slightly to the right of the centerline, which he corrected after touching down. Shortly afterward, the flight crew felt a vibration on the left side of the airplane. The vibration increased, and the airplane veered to the left despite the crew's efforts to maintain the airplane on the runway centerline. The airplane subsequently departed the paved runway surface and impacted the glideslope equipment building for runway 30, which was located to the left of runway 9, causing the nose landing gear and the right MLG to collapse. A

postcrash fire began on the right wing after the fuel tank on that wing was breached, after which the airplane came to a stop.

The flight attendants described the flight as “calm” and “normal” with some slight turbulence during the descent. The flight attendants reported that the initial touchdown was smooth but that, once the thrust reversers were activated (which they stated was “quicker than normal”), they felt vibrations and noted that it was “very loud” inside the cabin. The thrust reversers were suddenly “turned off,” which was followed by vibrations that were “very excessive,” and everything inside the cabin was “shaking violently.” The flight attendants realized that something was wrong and instructed passengers to remain seated and put their heads down. The airplane started “sinking on the left side,” and then the airplane stopped completely.

The flight crew initially instructed the passengers to remain seated. While performing the engine shutdown checklist, the crew learned, from the lead flight attendant, about smoke in the cabin, so the captain immediately commanded a passenger evacuation from the left side of the airplane, and the crew began performing the evacuation checklist. The evacuation and emergency response are discussed in the Survival Aspects section of this report. (As discussed in the evacuation information, one of the aft flight attendants had initiated the evacuation before the captain’s command.)

Video evidence (from an airport camera and a passenger’s cell phone) showed that the airplane touched down on runway 9 with about 8,900 ft remaining. Tire deposits on the runway, which started about 1,300 ft from the touchdown point, showed evidence of left MLG shimmy, which is a torsional vibration mode of the landing gear in which the inner cylinder oscillates relative to the outer cylinder. The amplitude of the shimmy increased steadily until the left MLG collapsed under the airplane with about 6,930 ft remaining on the runway. The airplane skidded on its left wing down the runway, veered to the left, and the right wing impacted a glideslope equipment building and antenna. The airplane’s nose gear and right MLG collapsed, and the airplane came to a stop. Figure 3 shows pertinent events during the accident landing.

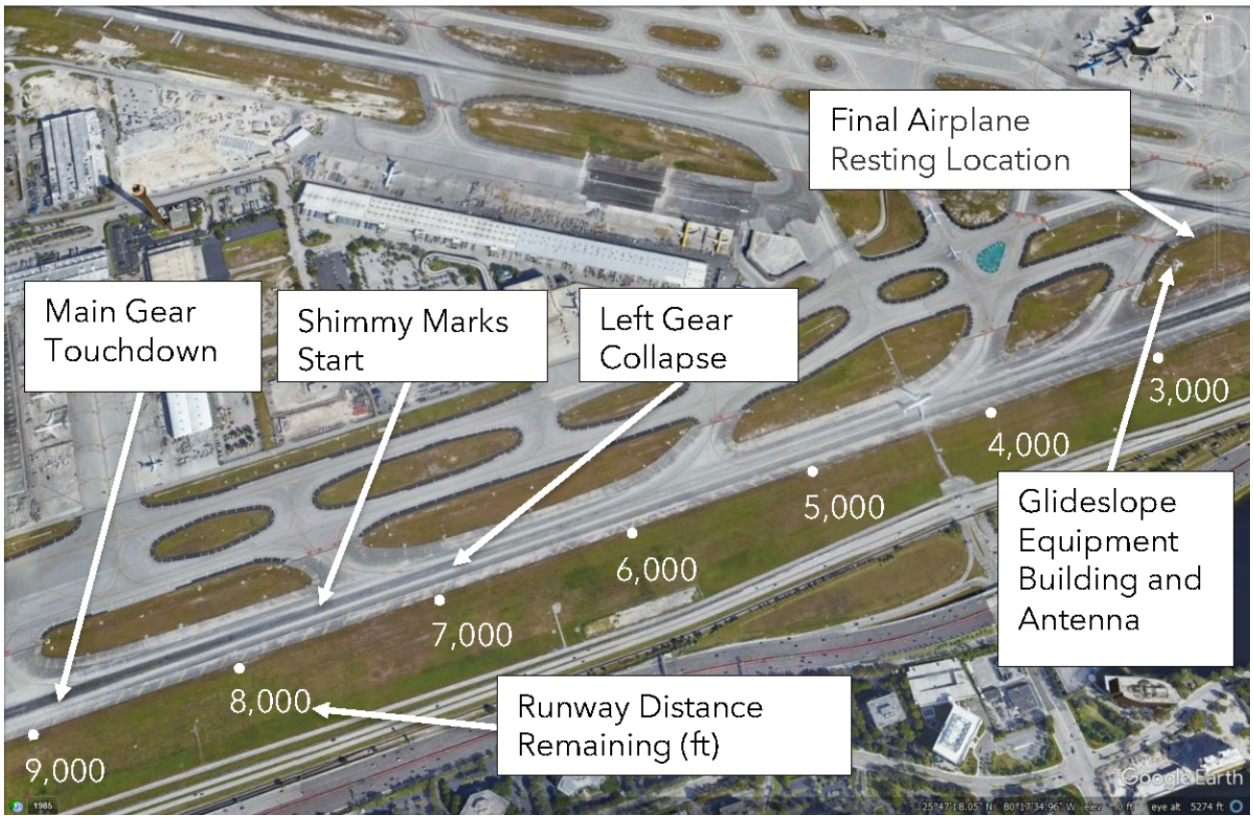

Figure 3. Overview of events during accident landing.

Note: Tire shimmy marks from the No. 1 tire were found with 7,480 and 7,120 ft of runway remaining. Tire shimmy marks from the No. 2 tires were found with 7,300, 7,200, and 7,020 ft of runway remaining.

Pilot Information

Certificate:	Airline transport	**Age:**	58,Male
Airplane Rating(s):	Single-engine land; Multi-engine land	**Seat Occupied:**	Left
Other Aircraft Rating(s):	None	**Restraint Used:**	
Instrument Rating(s):	Airplane	**Second Pilot Present:**	
Instructor Rating(s):	None	**Toxicology Performed:**	
Medical Certification:	Class 1 Without waivers/limitations	**Last FAA Medical Exam:**	March 15, 2022
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	May 17, 2022
Flight Time:	14388 hours (Total, all aircraft), 1400 hours (Total, this make and model), 9159 hours (Pilot In Command, all aircraft), 30 hours (Last 90 days, all aircraft), 15 hours (Last 30 days, all aircraft), 3 hours (Last 24 hours, all aircraft)		

Co-pilot Information

Certificate:	Commercial	**Age:**	28,Male
Airplane Rating(s):	Single-engine land; Multi-engine land	**Seat Occupied:**	Right
Other Aircraft Rating(s):		**Restraint Used:**	
Instrument Rating(s):	Airplane	**Second Pilot Present:**	
Instructor Rating(s):	Airplane multi-engine; Airplane single-engine	**Toxicology Performed:**	Yes
Medical Certification:	Class 1 Without waivers/limitations	**Last FAA Medical Exam:**	November 28, 2021
Occupational Pilot:	Yes	**Last Flight Review or Equivalent:**	
Flight Time:	822 hours (Total, all aircraft), 269 hours (Total, this make and model), 497 hours (Pilot In Command, all aircraft), 44 hours (Last 90 days, all aircraft)		

The captain's medical certificate required him to wear corrective lenses, and the captain stated that he was wearing contact lenses at the time of the accident. The first officer's medical certificate had no limitations. Post-accident drug and alcohol testing of both pilots identified no evidence of impairing drugs or alcohol.

Aircraft and Owner/Operator Information

Aircraft Make:	McDonnell Douglas	**Registration:**	HI-1064
Model/Series:	MD80	**Aircraft Category:**	Airplane
Year of Manufacture:	1990	**Amateur Built:**	
Airworthiness Certificate:	Transport	**Serial Number:**	54027
Landing Gear Type:	Retractable - Tricycle	**Seats:**	
Date/Type of Last Inspection:	March 3, 2022 Continuous airworthiness	**Certified Max Gross Wt.:**	150500 lbs
Time Since Last Inspection:		**Engines:**	2 Turbo jet
Airframe Total Time:	69529 Hrs as of last inspection	**Engine Manufacturer:**	Pratt and Whitney
ELT:	C126 installed, not activated	**Engine Model/Series:**	JT8D-219
Registered Owner:	Aircraft Leasing Inc	**Rated Power:**	21700 Lbs thrust
Operator:	Red Air, SA	**Operating Certificate(s) Held:**	Foreign air carrier (129)
Operator Does Business As:		**Operator Designator Code:**	OACI

General

The accident airplane, a McDonnell Douglas MD-82 (previously referred to as a Douglas Aircraft Company DC-9-82) was manufactured in 1990. The airplane was purchased by RED Air on February 15, 2021, and was registered in the Dominican Republic. According to RED Air maintenance records, the airplane had accumulated 69,838 hours and 36,990 cycles at the time of the accident. The airplane was powered by two Pratt & Whitney JT8D-219 engines, which were mounted on the aft fuselage.

The airplane was configured with 149 passenger seats and 8 exits: two exits forward of the wings (the L1 and R1 doors), four overwing window exits (two on each side of the airplane), one exit in the aft cabin (the L2 door), and one exit at the tailcone exit, as shown in figure 4. The L1, R1, and L2 doors and the tailcone exit were equipped with evacuation slides.

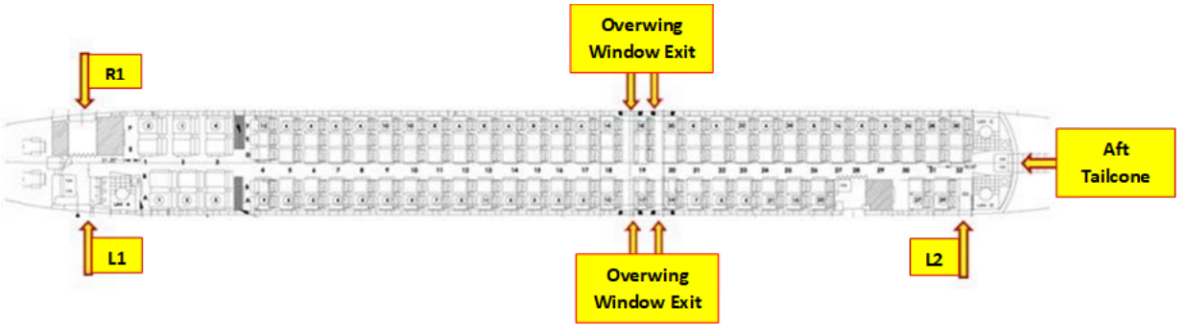

Figure 4. Location of exits (Source: RED Air). Labels added for clarity.

Main Landing Gear

The airplane's left and right MLG have outboard wheels (No. 1 wheel on the left gear and No. 4 wheel on the right gear) and inboard wheels (No. 2 wheel on the left gear and No. 3 wheel on the right gear). The MLG tires are mounted on the wheels. The airplane's antiskid system controls the hydraulic pressure applied to the brakes. The primary antiskid system components are the antiskid control unit, the antiskid control valves, and the wheel speed transducers (sensors),

The airplane is equipped with shimmy dampers on both MLGs to prevent excessive vibration or shimmy buildup in the gear during high-speed taxi and heavy braking. The shimmy damper is connected between the upper and lower torque links and allows a small but highly damped motion to occur around the torsional axis of the gear. Shimmy damper effectiveness is maximized when the MLG strut is compressed. Limited dampening capability is available when the MLG strut is fully extended. Figure 5 shows the landing gear torque links and the shimmy damper installation.

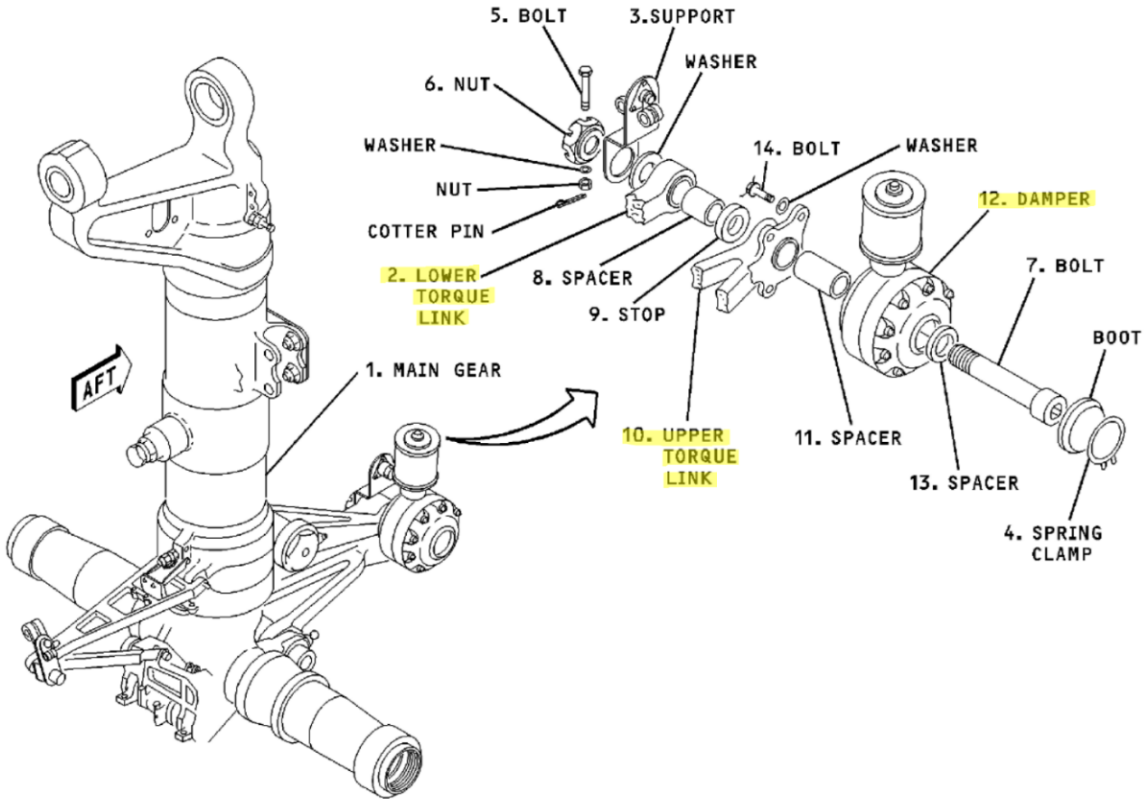

Figure 5. Shimmy damper installation. (Image copyright © Boeing. Reproduced with permission, highlighting added for emphasis).

The shimmy damper consists of a housing and a hydraulic reservoir, as shown in figure 6. The damper is a closed system that is separate from the airplane main hydraulic systems. The damper housing contains a piston that separates the two chambers and must be filled with hydraulic fluid for proper operation. As the piston moves back and forth between the chambers, the motion is dampened by orifices in the piston that restrict hydraulic fluid flow between the chambers. The damper has a Belleville spring arrangement that keeps the piston centered in the damper.

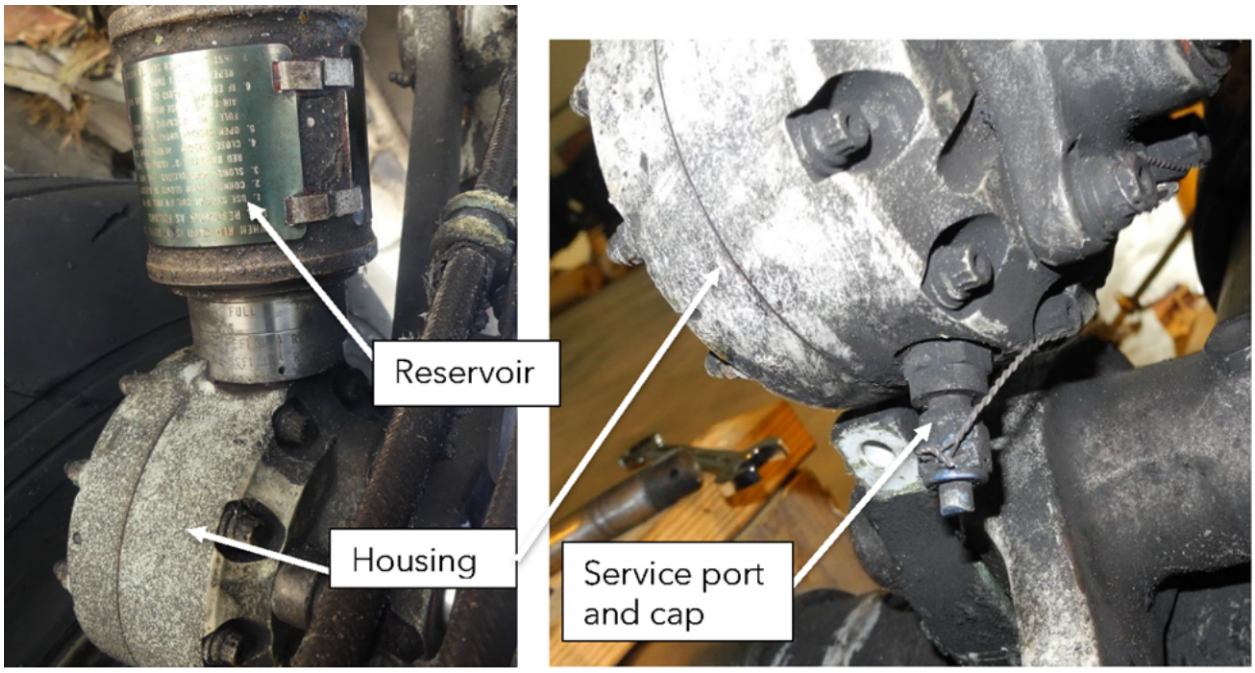

Figure 6. Right main landing gear shimmy damper housing, hydraulic reservoir, service port and service port cap.

The hydraulic reservoir is attached to the damper housing. The reservoir contains a spring that pressurizes the hydraulic fluid in the reservoir and damper to 40 to 55 pounds per square inch. A bleed port is located at the top of the reservoir, and a check valve, service port and cap are located at the bottom of the damper housing (see figure 7). Hydraulic fluid is added to either the bleed port or the service port through the check valve, and air in the damper is removed via the bleed port.

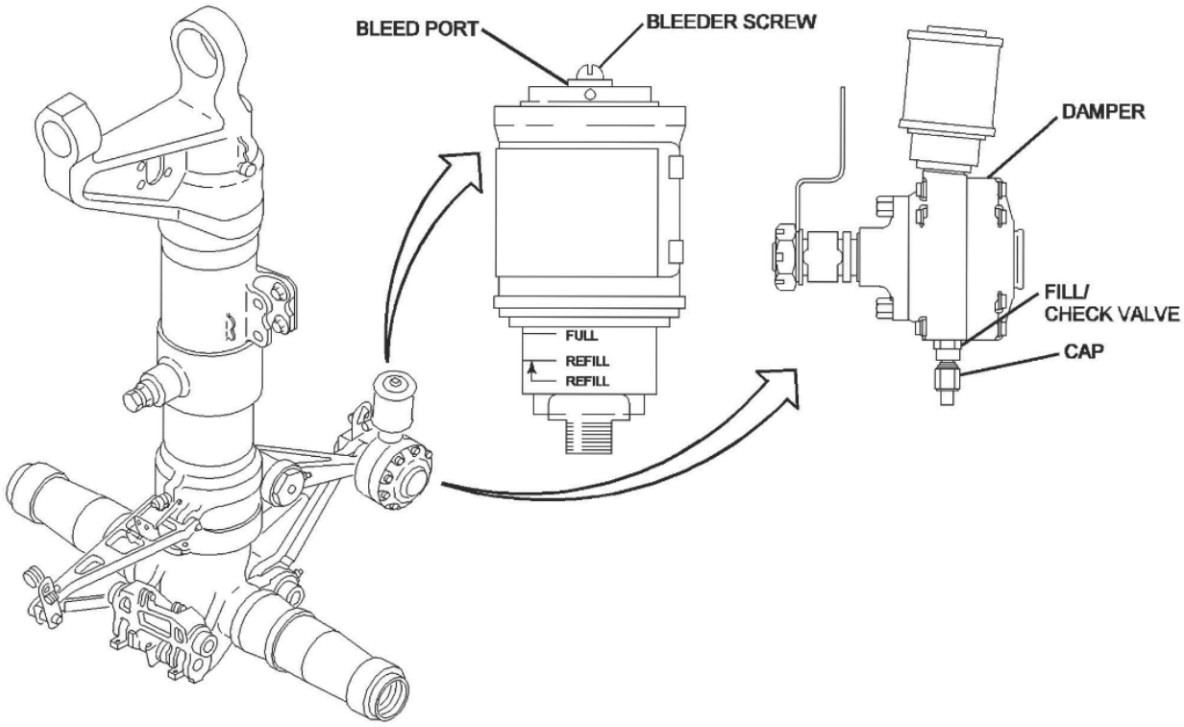

Figure 7. Graphic showing location of bleed port, check valve and cap. (Source: Image Copyright © Boeing. Reproduced with permission.)

Maintenance Program

The RED Air DC-9-82 maintenance program was approved by the Dominican Republic Civil Aviation Authority, the Instituto Dominicano de Aviacion Civil. The program was derived from several Boeing DC-9-82 documents and the Pratt JT8D-200 engine maintenance program. The RED Air maintenance program manual referenced FAA airworthiness directives for the DC-9-82. Review of the airplane's logbook (specifically, entries that were dated from March 21 to June 21, 2022) revealed normal routine maintenance/servicing of the airplane and no discrepancies or chronic issues with the landing gear. During a follow up visit to RED Air, additional documents were presented and showed a record of non-routine maintenance conducted where the left shimmy damper reservoir fluid level was low and it was refilled with hydraulic fluid.

The airplane's landing gear were overhauled by Suncoast Landing Systems, Medley, Florida, in August 2016. RED Air records showed that the left MLG had accumulated 35,405 cycles at the time of overhaul and that the next overhaul was due on August 3, 2026, or when the gear had accumulated 55,405 cycles, whichever came first.

According to the *Boeing MD-80 Maintenance Planning Document*, the airplane's nose and main gear wheel wells, which included the shimmy dampers, were required to be visually checked every 3 days for condition, security, and proper servicing. The RED Air maintenance program included a shimmy damper check during the airplane's "S" service, which consisted of a walk-

around inspection of the airplane to examine the condition and security of various components, look for discrepancies, and review the maintenance logbook. The “S” service on the accident airplane was last accomplished on the day before the accident (June 20, 2022). Maintenance records showed no anomalies concerning the last shimmy damper check.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	**Condition of Light:**	Day
Observation Facility, Elevation:	KMIA,5 ft msl	**Distance from Accident Site:**	2 Nautical Miles
Observation Time:	16:53 Local	**Direction from Accident Site:**	256°
Lowest Cloud Condition:	Few / 3000 ft AGL	**Visibility**	10 miles
Lowest Ceiling:	Broken / 25000 ft AGL	**Visibility (RVR):**	
Wind Speed/Gusts:	10 knots / 18 knots	**Turbulence Type Forecast/Actual:**	None / Unknown
Wind Direction:	50°	**Turbulence Severity Forecast/Actual:**	N/A / Light
Altimeter Setting:	30.08 inches Hg	**Temperature/Dew Point:**	30°C / 19°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	Santo Domingo, OF (MDSD)	**Type of Flight Plan Filed:**	IFR
Destination:	Miami, FL	**Type of Clearance:**	IFR
Departure Time:	19:00 UTC	**Type of Airspace:**	Class B

At 1753 (about 15 minutes after the accident), the MIA automated surface observing system reported wind from 050° at 9 knots gusting to 16 knots, visibility of 10 statute miles or greater, a few clouds at 3,000 ft above ground level (agl), a few clouds at 4,500 ft agl, broken ceiling at 25,000 ft agl, temperature of 30°C, dew point temperature of 16°C, and altimeter setting of 30.08 inches of mercury.

Airport Information

Airport:	MIAMI INTL MIA	**Runway Surface Type:**	Asphalt
Airport Elevation:	9 ft msl	**Runway Surface Condition:**	Dry
Runway Used:	9	**IFR Approach:**	ILS
Runway Length/Width:	13016 ft / 150 ft	**VFR Approach/Landing:**	None

MIA is located about 8 miles northwest of Miami, Florida. Runway 9/27 was constructed of grooved asphalt and was 13,016 ft long and 150 ft wide. The landing distance available was 11,397 ft.

Wreckage and Impact Information

Crew Injuries:	10 None	**Aircraft Damage:**	Substantial
Passenger Injuries:	4 Minor, 126 None	**Aircraft Fire:**	On-ground
Ground Injuries:		**Aircraft Explosion:**	None
Total Injuries:	4 Minor, 136 None	**Latitude, Longitude:**	25.800361,-80.275687(est)

The airplane was found resting on its fuselage with all landing gear collapsed, as shown in figure 8. The L1 and L2 doors were opened with their evacuation slides fully inflated. The forward right overwing window exit and both left overwing window exits were opened. The R1 door, tailcone, and aft right overwing window exits were not opened.

Figure 8. Airplane resting location as viewed from the left side.

The interior of the cabin was generally intact. The main aisle and areas leading to the floor-level exits were primarily clear with no visible buckling of the floor structure. The area near the overwing exits contained personal items (such as glasses, jackets, and baggage). The forward right overwing exit hatch was found on the cabin floor leaning against the seatbacks forward of the exit. One left overwing exit hatch was found on the trailing edge of the left wing, and the other left overwing hatch was found on the cabin floor.

Rubber deposits from the left MLG tires were found on the runway (see figure 9). These deposits grew in amplitude, indicating an increasing shimmy. The initial markings were continuous and were consistent with side-to-side oscillations. The markings became more arched and noncontinuous, consistent with the axle/wheels turning about the vertical axis. The markings then changed from a two-tire pattern to a single-tire pattern and were located on the opposite side of the runway centerline, consistent with the tire sidewall contacting the runway after the left MLG collapsed (see figure 2). The first debris located on the runway (about 1,840 ft from the touchdown point and with 7,060 ft of runway remaining) was a small piece of rubber that was later determined to be from the outboard side of the No. 2 tire.

Figure 9. Start of the left main landing gear shimmy marks. The distance noted is distance to the end of the runway.

Left Main Landing Gear

When the airplane was lifted during recovery, the left MLG dropped down to the extended position, and the axle was found to be rotated 90° outboard (with the No. 2 tire forward). The left MLG lower side brace fractured just below the joint of the upper and lower braces. The

lower end of the lower side brace remained attached to the outer cylinder. The upper side brace fractured into upper, middle, and lower pieces. The largest of the three pieces was the upper piece, which remained attached to the airplane (see figure 10). The middle and lower pieces were recovered in the debris field just past the glideslope building. The middle piece showed evidence of impact damage on its forward face. The lower piece had a small piece of black rubber, consistent with tire material, wedged in the joint.

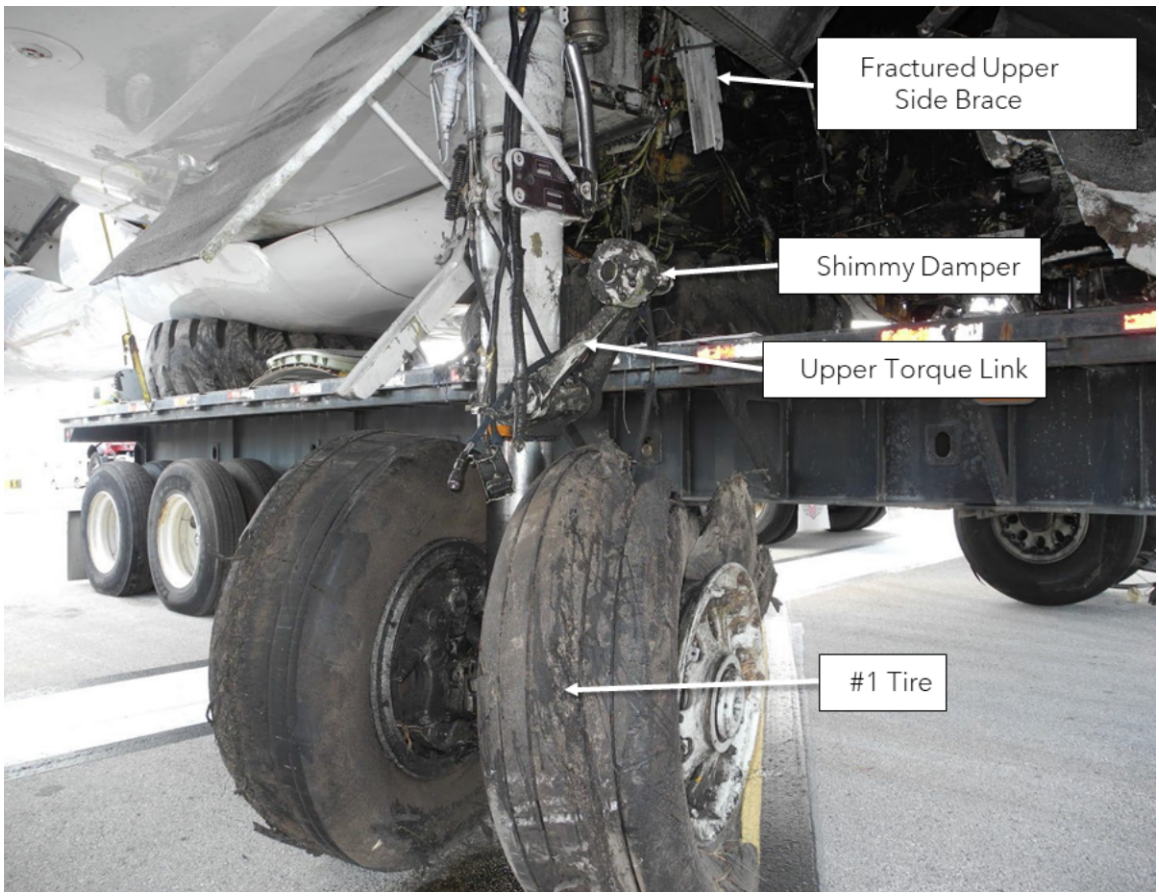

Figure 10. Photo of the left main landing gear after the accident looking inboard and slightly forward. Note that the landing gear assembly is facing outboard in the photo.

The upper torque link was intact and remained attached to the inner cylinder, but the upper end was fully fractured at the lug. The mating structure from the lower torque link lug remained attached to the apex bolt.

The MLG retract actuator piston was fractured. The retract actuator piston rod was in the extended position but was fractured at the interface with the cylinder. The piston rod was also bent. The down lock actuator and the upper lock link springs exhibited no damage, but the

lower lock fractured just inboard of its attachment to the upper side brace; the lower lock remained attached to the side brace.

Further examination of the left MLG found that all the fractures in the side braces and torque links occurred due to ductile separation consistent with overload; no evidence indicated fatigue failure. The damage on the forward side of the side brace aligned with damage on the outer cylinder near the gland nut, consistent with the side braces moving in the opposite direction of normal. The lower lock link was bent in the aft direction and was sheared. A small segment of the lower lock link, measuring about 3/16 inch, was missing. The upper lock link was bent in the forward direction with corresponding contact marks on the upper lock link and outer cylinder.

Shimmy Damper

The shimmy damper on the left MLG was missing its service port cap and hydraulic reservoir (see figure 11). The reservoir pieces were subsequently found in the grass area located about 200 ft north of the runway 9 centerline. The area where the reservoir was threaded into the damper housing had a large impact mark that deformed the area, and the threads were stripped.

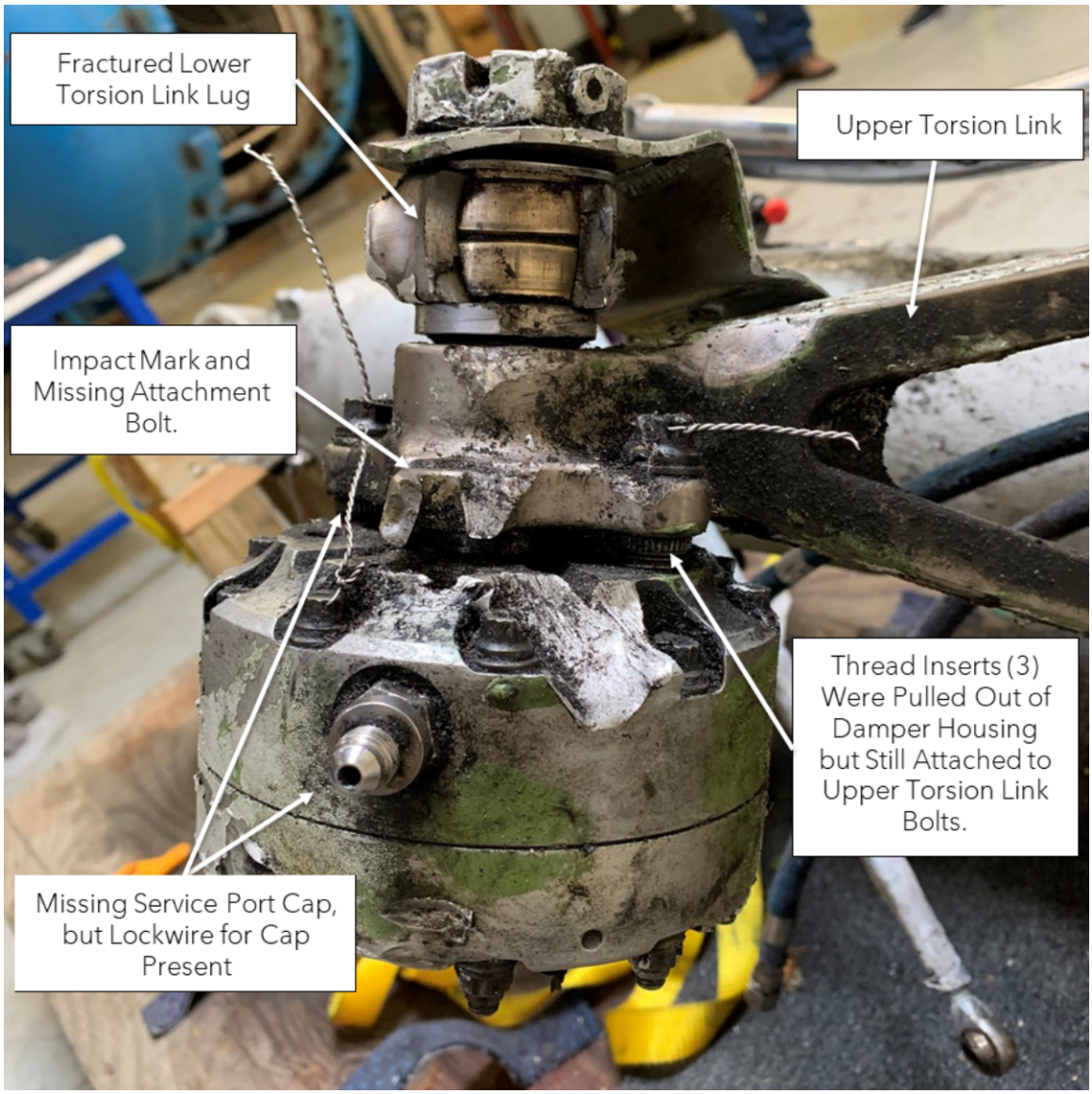

Figure 11. Left main landing gear shimmy damper as recovered.

Further examination of the shimmy damper revealed impact damage to the cap, housing, and several of the 10 housing bolts. Each bolt was numbered clockwise, with No. 1 as the bolt in the 9:00 position, and the reservoir was at the 12:00 position as viewed from the cap side. Breakout torque was measured for each housing bolt. The specified torque was between is 116 and 126 inch-pounds, but none of the measured torques were within that range.

The cap was removed, and the components on the cap side of the piston were removed and examined. All parts were found to be correctly installed and showed no apparent damage except for one of the five Belleville washers (the second one from the piston face), which was fractured due to ductile separation. The passages between the inner and outer orifices on the piston head were checked (with pressurized air) and found to be open.

The check valve/service port was removed from the housing, and the valve cap was not present. A lockwire was found on the nut for bolt No. 8 with an intact loop on the end that would have been connected to the service port cap. Breakaway torque was measured at 259 inch-pounds; nominal breakaway torque was 80 to 100 inch-pounds. The check valve passed the 5-pounds per square inch gauge (psig) allowable leakage rate test but failed the test performed at 1,000 psig. The valve was then cleaned, and the leakage tests were repeated, with the valve failing the tests at 5 and 1,000 psig. (The first test at 5 psig had a leakage rate of one drop/3 minutes, and the failed test at 5 psig had a leakage rate of two drops/3 minutes.)

The Belleville washer and the shimmy damper lockwire were examined at the NTSB's Materials Laboratory. The washer exhibited a through-thickness radial crack located in the 12:00 position. The opposite-facing fracture surfaces appeared rough and exhibited winding/twisting. The washer was sectioned and cleaned, and the fracture surface was examined using a scanning electron microscope. That examination showed that the elongated grain flow structure of the washer was oriented parallel to the washer's longitudinal direction (perpendicular to the fracture surface). A corner of the fracture surface of the washer exhibited a rougher and more fibrous surface. This area exhibited a 45° slant, consistent with a shear lip. A closer view of this area revealed a dimpled rupture on the corner and a cleavage fracture over the rest of the surface, which were consistent with the washer fracturing from overstress. The washer showed evidence indicating that it had been subjected to bending stresses.

The lockwire remnant was about 2 inches long, and the wire diameter measured 0.024 inches. The left end of the wire had a small loop, and the opposite right side had been separated. The loop surface exhibited three witness marks with an area of parallel rubbing or sliding lines along the same side. The closest distance between the witness marks was 0.085 inches, and the farthest distance (between the top and bottom of the loop) was 0.146 inches. An exemplar cap from the right shimmy damper was examined. The cap was hexagonal in shape and had three sets of holes at corners for wires. One of the holes exhibited wear and enlargement.

Tires and Brakes

Both tires on the left MLG were flat and missing significant portions of the tread. The Nos. 1 and 2 wheel assemblies were removed from the airplane and disassembled. The torque on each bolt was checked, and all bolts measured at least 155 inch-pounds (the minimum torque).

Examination of the internal liner of both tires revealed no circumferential wrinkles in the shoulder areas, which indicated that the tires were not significantly underpressurized. Numerous impact areas were observed on each tire with no flat spots or evidence of skidding in the tread area. The retread was well adhered. No evidence of poor tire maintenance was found.

The first piece of debris found on the runway was matched to the shoulder area on the outboard side of the No. 2 tire. The tire showed significant skidding on the sidewall on the inboard side around the entire circumference.

The brakes appeared to be undamaged, but debris was present. The brake wear indicator pins measured 0.5 inch (No. 1 tire) and 1 inch (No. 2 tire). The brakes were considered to be serviceable until the indicator pin was flush with the brake housing (0 inch).

Right Main and Nose Landing Gear

The right MLG collapsed into the wheel well and was in that position when the airplane came to rest. After the airplane was lifted during recovery, the gear dropped down. All components were intact and undamaged except for the bungee cylinder upper hydraulic tube, which was fractured, and the position of the lock links, which was slightly short of center.

The right MLG tires were found inflated with ample tread remaining; The Nos. 3 and 4 tires measured 191 and 190 psi, respectively; the allowable tire pressure for the airplane (based on a takeoff weight of about 135,600 pounds) was between 162 and 200 psi. The brake wear indicators measured 3/4 inch (No. 3) and 11/16 inch (No. 4). Numerous impact marks were found on both tires. The shimmy damper was intact with its service port cap installed and proper lock wiring (as shown previously in figure 4).

Substantial structural damage was observed to the nose wheel well. The nose landing gear was folded aft with its tires lodged in the forward electronics bay.

Antiskid System

The antiskid control unit quality seals were intact, and testing of the unit found no anomalies. Examination of the No. 1 (left outboard) wheel speed transducer found that one of the coupling arms to the hubcap was loose and longer than the other, indicating that the coupling arm had partially backed out. For the No. 2 (left inboard) wheel speed transducer, one of the coupling arms was slightly bent, and both coupling arms were partially backed out. Testing showed no issues with the output of the transducers. The lockwire did not conform to standards, indicating that the units might have been disassembled after production (even though no records showed that these parts had been returned to the manufacturer for servicing). Partial disassembly of the No. 1 transducer found that one of the internal wires had a dark brown deposit but that the wiring appeared to be undamaged under the deposit.

Both antiskid system control valves passed all tests except those related to the tolerances of the servo valve current versus the brake pressure. The antiskid control unit can compensate for these valve pressure differences, but slightly degraded antiskid performance could result

when the units were operating at peak control. The test results showed that the control valves could achieve full brake pressure dump, which would prevent a fully locked wheel condition.

Flight recorders

The airplane was equipped with an L3/Fairchild FA2100-1020 cockpit voice recorder (CVR), which was required by Title 14 *CFR* Part 129 to record a minimum of the last 30 minutes of aircraft operation. The accident CVR contained a two-channel recording of the last 2 hours of operation and a separate three-channel recording of the last 30 minutes of operation. The 2-hour portion of the recording comprised one channel that combined three audio panel sources and another channel that contained the cockpit area microphone. The 30-minute portion of the recording contained four channels of audio information: one each for the captain, the first officer, a cockpit observer, and the cockpit area microphone.

The audio information was extracted from the CVR without difficulty. The audio quality for the four channels on the 30-minute recording and the two channels on the 2-hour recording was poor or unusable. As a result of the poor or unusable quality of audio, only certain cockpit sounds and automated call outs were detected and transcribed. Crew comments were unable to be transcribed.

The airplane was also equipped with a Fairchild Model F1000 flight data recorder (FDR), which was required by Title 14 *CFR* 129.5(b) to record at least 32 parameters. The FDR recorded a minimum of 25 hours of flight data. The recorder was in good condition, and the data were extracted normally.The accident flight comprised about 2 hours 7 minutes of data, including a 16-second period in which the FDR did not capture data. The accident FDR did not record the time parameter in coordinated universal time; thus, a correlation from the FDR's subframe reference numbers to local times was initially not conducted. (The correlation was later accomplished as part of the aircraft performance study for this accident, which is discussed in the Tests and Research section of this report.)

Fire

There was a post-crash fire as a result of the right-wing making contact with a concrete and steel structure in the grassy area to the left of the runway. See the emergency response section for more details on the response to the fire.

Survival Aspects

The airplane cabin was configured as a two-class interior with 12 passenger seats (in rows 1 through 3) in business class and 137 passenger seats in economy class (in rows 4 through 32). The overwing window exits were located at rows 19 and 20.

Three seats were located in the flight deck: a captain seat, a first officer seat, and an observer seat that was directly forward of the flight deck door. Five cabin crew seats were installed: one double-occupancy aft-facing jumpseat adjacent to the L1 door, one single-occupancy aft-facing jumpseat forward of the L2 door, and one double-occupancy forward-facing jumpseat located on the aft tailcone interior door. The lead flight attendant and another flight attendant were assigned to the jumpseat at the L1 door, one flight attendant was assigned to the jumpseat at the L2 door, and one flight attendant was assigned to the jumpseat on the aft tailcone door. Two flight attendants-in-training were also aboard the airplane.

In addition to the cabin exits described earlier, the flight deck had two escape windows, one on each side. Neither flight crewmember used the flight deck windows for egress; both crewmembers exited the flight deck through the flight deck door and then exited the airplane through the L1 door.

Evacuation

Before the airplane stopped, an aft flight attendant saw fire near the right wing (see figure 12). Within 2 seconds after the airplane stopped, the aft flight attendants initiated an evacuation because of the fire. (The flight attendants had not heard anything at this point from the flight deck about evacuating.) One aft flight attendant immediately blocked his assigned door (the tailcone exit) due to the fire on the right wing (consistent with procedures) while the other aft flight attendant assessed the conditions outside her assigned door (L2), verified that the door was armed, and opened it. She stood back to let the slide inflate automatically and held back passengers who were trying to get out. The flight attendant then braced herself and shouted “sit, slide, and get away from the airplane.” She then heard the captain announce over the public address system “evacuate left side.”

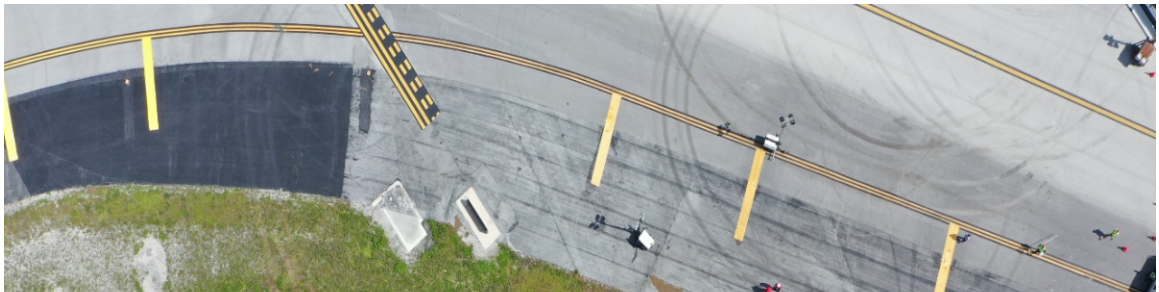

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Figure 12. Overhead image of the wreckage captured by NTSB's small UAS. The fire damage to the right wing is indicated by the yellow circle.

The other aft flight attendant stated that the passengers were "desperate" to get out of the airplane due to the fire but that they cooperated and listened to commands. This flight attendant also stated that passengers opened the overwing window exits without prompting. He further stated that, during the evacuation, he noticed some passengers were holding luggage and had to direct them to leave their bags and evacuate. This flight attendant blocked the opened right-side overwing window exits and directed passengers to the left-side exits.

The lead flight attendant reported hearing passengers in the back of the airplane yelling "fire." She did not see fire or smoke but could smell the smoke. The lead flight attendant informed the captain of a fire in the rear of the airplane, and the captain announced on the public address system, "evacuate, evacuate, left side." The lead flight attendant and the other forward flight attendant opened the L1 door, the slide inflated automatically, and passengers began evacuating from that exit.

According to video evidence and flight attendant postaccident interviews, up to three passengers used the forward right overwing window exit before the fire started. The other passengers used the L1 and L2 doors and both left overwing window exits for egress; the aft right overwing window exit and the tailcone exit were not used during the evacuation. The two

flight attendants-in-training provided assistance to special-assist passengers; the manifest for the flight (as well as postaccident interviews) indicated that 11 special-assist passengers were aboard the airplane.

The lead flight attendant thought that the evacuation was “quick” and took about 50 seconds. She evacuated the airplane after all the passengers and the other flight attendants were off the airplane. The captain walked through the cabin to ensure that all passengers and cabin crew were off the airplane, and then he and the first officer evacuated the airplane.

Emergency Response

ARFF personnel reported seeing fire and heavy smoke while en route to the accident site. The first ARFF truck arrived on scene within 1 minute of notification. ARFF personnel also reported that, when they first approach the site, passengers had already begun evacuating the airplane from the left overwing window exits and the L2 door; the L1 door was opened about 5 seconds after ARFF personnel arrived on scene. The fire was coming from the middle of the right wing and beneath the engine and tail, and the ARFF truck was positioned on the right side of the airplane near the wing and facing the tail. The ARFF personnel began efforts to extinguish the fire on the right side by deploying firefighting agent before the truck had come to a stop.

The next ARFF truck to arrive on scene was positioned near the R1 door, and ARFF personnel aboard that truck began efforts to extinguish the fire. By the time that the incident commander arrived on scene, both ARFF trucks had already begun cooling the fuselage and knocking down the fire. The fire was under control within about 10 to 15 minutes.

The four passengers who sustained minor injuries were transported to local hospitals. Buses transported the other airplane occupants from the tarmac. One of the firefighters observed passengers evacuating the airplane with their luggage and others recording the event with their cell phones.

Postaccident Examination of R1 Slide

The R1 exit, which was not used during the evacuation, was opened as part of this investigation. The exit opened easily, the slide deployed automatically once the door was fully opened, but the slide deflated after 3 minutes. The slide was subsequently sent to the manufacturer of the slide system (Safran AeroSystems Evacuation, Belmar, New Jersey) for examination, which found that the slide deflated because of a tear on the upper section seam of the side tube on the left side of the slide. The tear occurred due to the deterioration of the adhesive bond within the seam. The deterioration of the adhesive bond was due to the slide’s age at the time (22.5 years).

Specific inspections are recommended in the “Extended Maintenance” protocol in the Component Maintenance Manual for slides that are more than 15 years old. The intent of these inspections is to identify slides that should be taken out of service. In the case of the slide at the R1 exit, the slide manufacturer stated that “the weakness of the seam in the side tube may not have been apparent during the last maintenance event” but that “the slide

assembly did have several areas of questionable adhesion of cemented seams and components that should have been sufficient to remove it from service."

Tests and Research

An aircraft performance study was performed for this accident. The objectives of the study were to (1) document video evidence related to the accident flight, (2) verify the location where the MLG touched down on the runway, and (3) determine the airplane's flightpath and ground track. The study used the available automatic dependent surveillance-broadcast (ADS-B) and FDR data, CVR information, and video and survey evidence. The available FDR data indicated that the airplane was configured for a flaps 28 landing and that the wheel brake pressure was increasing after MLG and nose gear touchdown. Pertinent CVR information appears in the table below.

Table. CVR events after the 10-ft automated voice callout before touchdown.

Time	Recorded CVR information
1738:01	Sound of mechanical squeal
1738:02	Sound of light “thunk”
1738:05	Sound of second light “thunk”
1738:07	Sound of increasing shimmy, and sound similar to airplane sliding begins
1738:11	Automated voice callout “landing gear”
1738:37	Sounds of loud thuds
1738:43	Sound similar to airplane sliding ends

Note: The 10-ft automated voice callout occurred at 1737:56. The CVR recording ended at 1739:12.

Regarding the video evidence, eight external video surveillance cameras (from various locations at MIA) and one cellular telephone video (from a passenger aboard the airplane) recorded a portion of the accident flight. The video camera footage was separated into individual image frames, which were placed in chronological order to determine the image content that would be pertinent to the investigation. The videos showed that ground-level visibility appeared to be clear and that the taxiway and runway pavement surface conditions appeared to be bare and dry.

The study used the results of the NTSB’s drone aerial survey of runway 9, which documented witness marks and the airplane’s resting location. The study also constructed a flightpath model of the landing event (from short final approach to the airplane’s resting location) using information from the drone survey of the runway; ADS-B data; FDR data, including integrated accelerometer data; CVR information; and calculated distance markers from the runway 9 displaced threshold.

The study results showed that MLG gear touchdown occurred about 2,750 ft beyond the runway 9 displaced threshold, which was within one-third of the landing distance available.

Organizational and Management Information

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Administrative Information

Investigator In Charge (IIC):	Silva, Sathya
Additional Participating Persons:	Patrick Lusch; FAA; Washington, DC Nathan Williams; The Boeing Company; Everett, WA Omar Ricardo; Miami-Dade Fire Rescue; Miami, FL
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