June 24, 2025 Aviation Investigation Report AIR-25-04

In-Flight Separation of Left Mid Exit Door Plug, Alaska Airlines Flight 1282, Boeing 737-9, N704AL

Portland, Oregon

January 5, 2024

Abstract: This report discusses the January 5, 2024, accident involving a Boeing 737-9 airplane operated by Alaska Airlines that experienced an in-flight separation of the left mid exit door (MED) plug and rapid depressurization during climb after takeoff from Portland International Airport. One flight attendant and 7 passengers received minor injuries; the captain, the first officer, 3 flight attendants, and 164 passengers were uninjured; and the airplane sustained substantial damage. Safety issues identified in this report include the circumstances of the airplane's manufacture at Boeing Commercial Airplanes' Renton, Washington, manufacturing facility that led to opening of the left MED plug without the required removal record to ensure that removed bolts and attachment hardware were properly replaced; the complexity of Boeing's business process instruction (BPI) for parts removals and its inadequate training of manufacturing personnel; Boeing's ineffective change management related to workforce experience level decreases; Boeing's ineffective corrective actions and the Federal Aviation Administration's (FAA) ineffective oversight that allowed the persistence of issues with Boeing's BPI for parts removals; the need for Boeing to improve quality escape mitigation strategies and continue development of its safety management system; the need for hands-on emergency oxygen mask training for flight crews; the need for portable oxygen bottle design standards review; the need for effective operator procedures and 25-hour cockpit voice recorder (CVR) installations and retrofits to prevent the loss of CVR audio; and the safety benefits of using child restraint systems for children under the age of 2 years. As a result of this investigation, the National Transportation Safety Board makes 11 recommendations to the FAA and 8 recommendations to The Boeing Company, and reiterates 4 safety recommendations to the FAA and 1 safety recommendation to Airlines for America, the National Air Carrier Association, and the Regional Airline Association.

Contents

Figures

Tables

Acronyms and Abbreviations

ACAIS	aircraft certification audit information system
AD	airworthiness directive
BPI	business process instruction
CMES	common manufacturing execution system
CFR	*Code of Federal Regulations*
CPC	cabin pressure controller
CRS	child restraint system
CVR	cockpit voice recorder
DOT	Department of Transportation
FAA	Federal Aviation Administration
FAM	flight attendant manual
FCOM	flight crew operations manual
FDR	flight data recorder
IP	installation plan
KPI	key performance indicator
MED	mid exit door
MOM	multi-operator message
NCO	nonconformance order
NCR	nonconformance record
NG	next generation
NPRM	notice of proposed rulemaking
NTSB	National Transportation Safety Board
OIG	Office of Inspector General
ONT	Ontario International Airport
PDX	Portland International Airport
QAR	quick access recorder
QMS	quality management system

QRC	quick reference checklist
QRH	quick reference handbook
RBRT	risk-based resource targeting
SAT	Shipside Action Tracker
SMS	safety management system
SRM	safety risk management
UART	universal asynchronous receiver-transmitter
VSMS	voluntary safety management system

Executive Summary

What Happened

On January 5, 2024, a Boeing 737-9 airplane operated by Alaska Airlines as flight 1282 experienced an in-flight separation of the left mid exit door (MED) plug and rapid depressurization when climbing through about 14,830 ft after takeoff from Portland International Airport (PDX), Portland, Oregon. One flight attendant and 7 passengers received minor injuries; the captain, the first officer, 3 flight attendants, and 164 passengers were uninjured; and the airplane sustained substantial damage. The flight and cabin crews executed the emergency procedures in response to the rapid depressurization, and the flight returned to PDX for a safe landing.

The airplane had a hole in the fuselage where the left MED plug (a rectangular airframe structure about 29 inches wide and 59 inches high) had been installed. Components on the fuselage frame that surrounded the hole, including fittings and assemblies associated with the left MED plug installation, were damaged. The passenger seats and cabin interior located nearest the hole were also damaged, and a seatback tray table, two seat headrests, and cabin interior panels were missing. The airplane's left MED plug and some of the seat and interior pieces were located on the ground (along the airplane's flight path) and recovered. Multiple components associated with the left MED plug installation, including four bolts that would secure the left MED plug from moving upward vertically, were not located.

What We Found

The National Transportation Safety Board found that the four bolts that secured the left MED plug to prevent it from moving upward vertically were missing before the newly manufactured airplane was delivered to Alaska Airlines. As a result, the left MED plug was able to become displaced gradually upward (by fractions of an inch) during previous flights until, during the accident flight, it displaced upward enough to disengage from its stop fittings and separate in flight. The upward displacement before the accident flight would not have been detectable during a routine preflight inspection, and there was no evidence this upward displacement was associated with previous pressurization system AUTO FAIL light illumination events.

We determined that, when the airplane was manufactured, Boeing personnel had opened the left MED plug (which inherently required removing the four bolts and associated hardware) to allow access for rivet rework to be performed on the edge frame forward of the left MED plug. However, opening an MED plug was a nonroutine task, and no personnel experienced with opening or closing an MED plug were on duty at the times that the accident airplane's left MED plug was opened and closed, and none said they had any knowledge of who opened it.

We found that, per Boeing's Business Process Instruction (BPI) for performing parts removals, opening an MED plug, because it was a disturbance of a previously accepted installation, required the generation of a removal record. The purpose of a removal record was to document that parts were removed from the airplane and to specify the tasks and quality assurance signoffs required to ensure that the installation was subsequently restored to an accepted condition. However, we found that no removal record was generated. The left MED plug was subsequently closed without its securing bolts and attachment hardware, and no quality assurance inspection of the plug closure was performed.

In addition, Boeing's short stamp process, which was intended to document the work that needed to be deferred or "traveled" to allow for the rivet rework, was not correctly applied for the accident airplane. We found that, although the short stamp process does not negate the need to generate a required removal record for disturbed installations, had the short stamp process been correctly applied, it may have provided an opportunity for personnel to detect the left MED plug's missing bolts and attachment hardware.

We also found that Boeing's BPI for performing parts removals lacked the clarity, conciseness, and ease of use necessary to be an effective tool for workers in the manufacturing process. The BPI had a documented history of compliance issues for at least 10 years before the accident. However, Boeing's corrective actions to address the issues, which were accepted by the Federal Aviation Administration (FAA), were ineffective to address the persistent deficiencies with the BPI.

We also found that Boeing's on-the-job training for generating removal records was insufficient, which decreased the likelihood that personnel with limited exposure to nonroutine tasks could correctly open an MED plug and generate the required removal record.

We found that the Federal Aviation Administration's (FAA) compliance and enforcement surveillance, audit planning procedures, and records systems were deficient and lacked the functionality necessary to identify repetitive and systemic discrepancies and nonconformance issues with the BPI for parts removals. Also, Boeing's quality escape guidance did not adequately address controls for human error, and its voluntary safety management system, which was still being developed at the time the accident airplane was in production, did not proactively identify the risk of the quality escape that occurred. We determined that, for Boeing's future implementation of its regulatory safety management system (SMS) and integration into its quality management system to be successful, accurate and ongoing data about its safety culture is needed.

We also found that the circumstances of this accident and others in which the flight crew faced communications challenges associated with oxygen mask use highlighted the need for hands-on, aircraft-specific training and procedures for the use of each type of oxygen system in an operator's fleet. We also identified the need for the FAA to review the design standards for portable oxygen bottles to ensure that they adequately address ease of use.

Further, the circumstances of this accident emphasized the need for effective operator procedures for preserving cockpit voice recorder (CVR) data after an accident or incident occurs, as well as the continued need for installations and retrofits of CVRs with a 25-hour recording capability. We found it continues to be necessary to address these issues because valuable information continues to be overwritten on CVRs that are designed to record only 2 hours of audio data. Finally, although the three lap-held children on board the accident airplane did not sustain any injuries, we found that the potential for severe injury or death existed and reinforced the prudence of using a child restraint system (CRS) for children less than 2 years old appropriate to their size and weight.

We determined that the probable cause of this accident was the in-flight separation of the left MED plug due to Boeing's failure to provide adequate training, guidance, and oversight necessary to ensure that manufacturing personnel could consistently and correctly comply with its parts removal process, which was intended to document and ensure that the securing bolts and hardware that were removed from the left MED to facilitate rework during the manufacturing process were reinstalled. Contributing to the accident was the FAA's ineffective compliance enforcement surveillance and audit planning activities, which failed to adequately identify and ensure that Boeing addressed the repetitive and systemic nonconformance issues associated with its parts removal process.

What We Recommended

As a result of this investigation, we made safety recommendations to the FAA and Boeing.

We recommended that the FAA revise its compliance enforcement surveillance system, audit planning activities, and records systems to ensure that they provide the necessary functionality for FAA managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes. We also recommended that the FAA develop guidance and provide recurrent training to those managers and inspectors.

We also recommended that the FAA retain historical compliance enforcement and audit records older than 5 years and provide FAA managers and inspectors access to these records to enhance their oversight planning for production approval holders. In addition, we recommended that the FAA convene an independent panel to conduct a comprehensive review of Boeing's safety culture, such that the findings should be used to enhance Boeing's ongoing development of its regulatory SMS and the integration of its SMS into its broader quality management system.

Additionally, we recommended that the FAA notify operators of the circumstances of this accident, and encourage them to review their flight crew training programs and ensure that they provide hands-on, aircraft-specific training and procedures for each type of oxygen system in the operators' fleet, to include establishing and maintaining communications when oxygen masks are donned and removed while participating in realistic emergency procedures training scenarios. We further recommended that the FAA review and revise, as necessary, the design standards for portable oxygen bottles.

We also recommended that the FAA require operators of airplanes equipped with a CVR to incorporate guidance into company standard operating procedures, emergency protocols, and postincident and postaccident checklists—applicable to both flight crew and non-flight crew personnel—detailing actions to preserve CVR recordings as soon as practical following a flight with a reportable event.

We recommended that Boeing continue the certification process for the design enhancement for MED plugs to ensure that, once the design enhancement is certified, all applicable newly manufactured airplanes are equipped with the enhancement. We also recommended that Boeing issue a service bulletin to address retrofitting in-service airplanes. We also recommended that the FAA issue an airworthiness directive to require that all in-service MED plug-equipped airplanes be retrofitted with the design enhancement.

We also recommended that Boeing revise its BPI for parts removals to include clear and concise guidance for determining when a removal record is needed and develop recurrent training for manufacturing personnel that emphasizes the importance of removal records for product safety, prepares personnel to consistently and correctly determine when a removal record is needed, and ensures that a removal record is generated when required.

We recommended that Boeing develop a structured on-the-job training program that identifies and defines tasks necessary for manufacturing personnel to be considered fully qualified in their job series and includes a grading system for trainers and trainees to track progression and determine competence. We also recommended that Boeing document and archive the training provided and received to support future data analysis.

We recommended that Boeing revise its safety risk management process to ensure that it identifies the root causes of compliance issues, like the persistent deficiencies with the BPI for parts removals and other production process inconsistencies and evaluate the effectiveness of corrective actions.

We also recommended that Boeing develop a process that can identify escapes that result from human error, assess them using a system specifically designed to identify factors that contribute to such errors, and implement effective mitigation strategies.

In addition, we reiterated our previously issued safety recommendations to the FAA related to requiring a CVR capable of recording the last 25 hours of audio (for all airplanes already required to be equipped with both a CVR and a flight data recorder); conducting a study to determine the factors, including any challenges, that affect caregivers' decisions about using CRSs when traveling with children under the age of 2 on aircraft operated under Part 121; and using the study's findings to direct the FAA's efforts to increase CRS use.

We also reiterated our previously issued safety recommendations to the Airlines for America, the National Air Carrier Association, and the Regional Airline Association related to coordinating with their member airlines to develop and implement a program to increase CRS usage in airplanes and collecting data to determine the program's effectiveness at increasing CRS use.

1 Factual Information

1.1 History of the Flight

On January 5, 2024, about 1713 Pacific standard time, Alaska Airlines flight 1282, a Boeing 737-9 airplane, N704AL, experienced an in-flight separation of the left mid exit door (MED) plug and rapid depressurization during climb after takeoff from Portland International Airport (PDX), Portland, Oregon.[1] One flight attendant and 7 passengers received minor injuries; the captain, the first officer, 3 flight attendants, and 164 passengers were uninjured; and the airplane sustained substantial damage. The scheduled domestic passenger flight was operated under Title 14 *Code of Federal Regulations* (*CFR*) Part 121 and departed PDX about 1707 with a planned destination of Ontario International Airport (ONT), Ontario, California.[2]

According to flight crew interviews, the accident flight was the first leg of the captain and first officer's 1-day pairing for a round trip from PDX to ONT. The first officer performed the external preflight walkaround and observed nothing abnormal about the airplane exterior except ice on the wing. The first officer called for an ice check, and the airplane was subsequently deiced.

The captain, who was in the left seat and was the pilot flying, conducted the departure briefing with the first officer. In the cabin, the flight attendants conducted the passenger safety briefing. The pilots and the flight attendants reported that the flight's taxi, takeoff, and initial climb were uneventful.[3] The flight crew checked in with

[1] (a) The Boeing 737-9 is part of the Boeing 737 MAX family of airplanes (see sections 1.5.1 and 1.11.1 for more information). It is manufactured by Boeing Commercial Airplanes, a business unit of The Boeing Company, which holds the type certificate for the airplane. In this report, "Boeing" refers to Boeing Commercial Airplanes, unless otherwise indicated. (b) An MED plug is a rectangular airframe structure, about 29 inches wide and 59 inches high, that is installed in a fuselage opening and secured in place by bolts and other hardware. See section 1.5.2 for more information. (c) The term "depressurization," which refers to a loss of cabin pressure, is used interchangeably with the term "decompression" in transport-category airplane regulations and Alaska Airlines' procedures. For consistency, this report uses the term "depressurization," unless quoting a source that uses decompression. (d) Visit ntsb.gov to find additional information in the NTSB public docket page for this NTSB accident investigation (case DCA24MA063). Use the CAROL Query to search safety recommendations and investigations.

[2] All times in this report are Pacific standard time.

[3] Event sequence descriptions are based on flight and cabin crew interview information correlated with the timing of events recorded by the flight data recorder (FDR). The cockpit voice recorder (CVR) recording contained no audio from the accident flight (see section 1.8.1 for more information).

the Seattle Air Route Traffic Control Center and received a climb clearance to flight level 230 to the next waypoint.[4]

FDR data showed that, at 1712:33, the airplane was climbing through about 14,830 ft when the cabin pressure dropped, and the cabin altitude warning activated, followed 1 second later by the master caution alert.[5] According to the captain, he heard a "loud bang," his ears popped, his head was "pushed" forward, and his communications headset was pushed nearly off. The first officer stated that her ears popped and that, simultaneously, the flight deck door blew open, her headset blew off (due to the rapid outflow of air from the flight deck), and the cabin altitude warning horn sounded.

The captain and the first officer immediately retrieved their emergency oxygen masks from their respective stowage boxes (outboard of each seat in the side console) and donned them. (Each oxygen mask, which was designed to automatically provide oxygen flow when unstowed, was equipped with an internal, dynamic microphone that automatically activated to enable crew radio transmissions when the mask was in use.[6]) Donning the emergency oxygen masks and establishing communications were the first two steps in Alaska Airlines' "CABIN ALTITUDE WARNING or Rapid Depressurization" emergency procedure. Alaska Airlines' quick reference checklist (QRC) and the quick reference handbook (QRH) for the airplane each highlighted these steps as memory items (with a bold black box around the text), and both crewmembers initiated and completed the steps from memory before retrieving the checklist.

The first officer said that she saw in her peripheral view (through the open flight deck door) that the cabin oxygen masks had dropped. She said she saw the hand of a flight attendant shut the flight deck door, and it stayed shut for the

[4] Flight level refers to pressure altitude stated in three digits representing hundreds of ft. Pressure altitude refers to the altitude of the airplane above a standard reference datum of 29.92 inches of mercury; that is, it is the altitude displayed on the airplane's barometric altimeter when the altimeter is set to this standard pressure. (For example, flight level 230 represents a barometric altimeter indication of 23,000 ft when the altimeter is set to standard pressure.) All altitudes referenced in this report are pressure altitude.

[5] The "Cabin Altitude Greater than (>) 10k ft Warning" included the illumination of warning lights on the panel (one in front of each pilot) and a continuous audible warning horn.

[6] The first officer said that she initially reached toward the audio control panel for the manual microphone selector (MASK-BOOM switch, a Boeing 737 NG feature) before remembering that the oxygen mask microphone is automatically selected in the Boeing 737 MAX when the mask is unstowed (see section 1.11.1.1 for more information about the Boeing 737 MAX and NG emergency oxygen mask procedures differences).

remainder of the flight.[7] The captain described the rapid depressurization event as "an explosive experience," and the first officer stated, "it was chaos."

According to flight attendant D, she had just gotten up from her seat to unlock the forward lavatory when the flight deck door opened forcefully and struck her, bruising her right arm and knee (see next section).[8] She sat back down (on the dual jump seat she shared with flight attendant A), held onto her seat restraint, and struggled to close the flight deck door. All four flight attendants donned oxygen masks, which had dropped from the compartments above their seats. A prerecorded automated announcement played in the cabin for passengers and flight attendants in both English and Spanish to put on their oxygen masks, remain seated, and ensure seat belts were fastened. All four flight attendants reported that it was very loud in the cabin due to the noise of rushing air.

According to the captain, he asked the first officer to declare an emergency with air traffic control and request a lower altitude. According to the first officer, she used the audio control panel (located on the center control stand) to select the overhead speaker, turned up the volume, and contacted air traffic control to declare an emergency. Both pilots stated that it was very loud on the flight deck, making it difficult to hear each other and the air traffic controller.

The captain said he disconnected the autopilot and autothrottles, began a descent to 10,000 ft, and called for the rapid depressurization checklist. FDR data showed that, at 1713:41, the airplane reached its maximum altitude of 16,320 ft then began to descend (about 1 minute after the cabin pressure had dropped), and at 1713:56, the airplane's selected altitude changed from 23,000 ft to 10,000 ft. As the airplane descended, the cabin pressure increased.[9]

The first officer stated that she pushed the altitude warning horn cutout switch to cease the continuous audible warning. She said she reached to the top of the glareshield panel to retrieve the quick reference checklist (QRC) from its holder, but it was not there. (The first officer did not recall seeing loose items in the flight deck fly by her during the rapid depressurization, but, after landing, the first officer found the QRC behind her seat.) The captain retrieved the quick reference handbook (QRH)

---

[7] The flight and cabin crews were unaware that the flight deck door was designed to open during a rapid depressurization in the cabin. This design feature was not documented in the applicable Boeing or Alaska Airlines manuals (see sections 1.5.3 and 1.12.4 for more information).

[8] Alaska Airlines used the letters A through D to identify the four flight attendant duty positions. When the accident flight departed, flight attendants A and D were seated next to the left forward cabin door (door L1), and flight attendants B and C were seated adjacent to the left and right aft cabin doors (doors L2 and R2), respectively (see section 1.9 for more information).

[9] Calculations performed using the available FDR data determined that the maximum cabin pressure altitude was about the same.

from the control stand's left side, and the first officer used it to reference the rapid depressurization emergency procedure, reading it out loud while handling communications with air traffic control. The captain asked the first officer to request a return to PDX, which she did, and the air traffic controller provided a heading.

The captain stated that he heard (over the cabin interphone) the flight attendants talking about a "hole" in the cabin, and he tried to communicate with them (using the oxygen mask microphone and the cabin interphone button on the audio control panel) multiple times, but they didn't respond, and he was unsure whether they could hear him. He reengaged the autopilot and autothrottles, continued the descent, and turned back toward PDX on the assigned heading. The captain said that, right about the time the airplane's descent reached 10,000 ft, the first officer had completed the emergency descent checklist. FDR data indicated that the airplane descended below 10,000 ft at 1717:00, and, at 1718:05, the "Cabin Altitude Greater than (>) 10k ft Warning" deactivated.

Flight attendant A (who was seated in the forward cabin) stated he used the interphone to try to communicate with the pilots, but the noise was so loud in the cabin that he did not know whether they answered or even if they were okay. Flight attendant C (who was seated in the aft cabin) also reported that it was very loud in the cabin, but she was able to use the interphone to communicate with flight attendant A, who told her that there had been no contact with the flight crew.

Flight attendants D, B, and C used supplemental oxygen sources to move through the cabin to check on the four unaccompanied minors and reseat two passengers who were standing in the aisle.[10] During this time, flight attendant D saw the hole in the airplane where the left MED plug had been at row 26, and encountered a passenger who was standing and very upset, telling flight attendant D that she thought her son (age 15) "blew out" of the airplane.[11] Flight attendants D and B observed five vacant seats next to the hole at rows 26 and 25 (the row just forward of the hole) and believed that multiple passengers were lost.[12]

[10] Flight attendants D and B each used a portable oxygen bottle, and flight attendant C initially followed a mask-to-mask procedure, which involved using the extra oxygen mask at various passenger seat units as she moved forward through the cabin (see section 1.9 for more information).

[11] The flight attendants did not know until after landing that the passenger's son (who, according to passenger interviews, had originally been seated in seat 25A) had moved to a different seat after the event occurred. Passengers reported that the young man's shirt was pulled off his body during the rapid depressurization and that other passengers seated nearby lost belongings out the hole (see section 1.9 for more information).

[12] According to passenger interviews, the occupants of seats 25A, 25B, and 25C got up from their seats after the event (and before flight attendants D and B reached that row), and seats 26A and 26B were unoccupied. The passenger in seat 26C chose to remain in that seat after the event.

Flight attendant A used the interphone to communicate with the aft cabin flight attendants again and received information about the hole in the airplane and the possible loss of passengers. Flight attendant A said that he again tried to contact the flight deck to pass on the information and he believed one of the pilots answered, but he could not hear what was said. He assessed that supplemental oxygen was no longer needed, got up from his seat to assist in the cabin but felt "really, really hot air" about row 15 and returned to his seat to make more attempts to contact the flight crew. He said that he heard "very faint" audio of a pilot stating that the flight was returning to PDX.

The captain said that he continued to hear (over the interphone) the flight attendants discussing a hole in the cabin, so he wanted to land the airplane as soon as possible. He said that, because the airplane was already below 10,000 ft, he did not call for the emergency descent checklist but asked the first officer to prepare for the instrument landing system runway 28L approach to PDX. The captain said that he and the first officer had already briefed before takeoff that, if they had a problem, they would return to runway 28L and had the localizer and radio frequencies already set up. The first officer requested (and subsequently received landing clearance for) the runway 28L approach.

According to flight attendants D and C, after they assisted the passengers and returned to their seats, flight attendant A informed them (in person and via interphone, respectively) that the flight was turning around. Flight attendant A stated that he made an announcement to the passengers that they were returning to the airport. All four flight attendants secured themselves in their seats and mentally prepared for an evacuation.

The captain said he was still unsure whether the flight attendants could hear him, so he suggested to the first officer that they remove their oxygen masks to try to establish better communications. They removed their masks, put their headsets back on, and heard a loud noise through the earpieces that made it impossible for them to hear air traffic control and each other.[13] They removed their headsets, put their oxygen masks back on, and continued to use the oxygen mask microphone and overhead speaker for the remainder of the flight.

The captain said that, as the flight descended through about 6,000 or 7,000 ft, he saw that they were a little high on the approach, so he disengaged the autopilot

[13] For the accident airplane (and other Boeing 737 MAX airplanes in the Alaska Airlines fleet), after removing an oxygen mask, the crew had to close the right stowage box door and push the TEST/RESET switch on the stowage box to deactivate the mask microphone and reactivate the headset boom microphone (see section 1.11.1.1 for more information). The captain stated that he did not realize at the time that the noise coming through the headset (which he described as a "squeal" and the first officer described as "a very loud white noise") was from the still-active mask microphones.

"to start down to get back on path." The crew continued to configure the airplane for landing, and both pilots had the airport in sight. FDR data showed that the flight landed at 1726:46, about 14 minutes after the MED plug separated. Both pilots reported that the landing, rollout, and taxi to the gate were uneventful.

After landing, flight attendant A made an announcement for the passengers to remain seated, then called the flight deck, was able to hear the pilots, and was told that no evacuation was necessary. The pilots taxied the airplane to the gate, aircraft rescue and firefighting personnel and equipment were waiting, and paramedics boarded to assess any injuries and assist, as needed.

1.2 Injuries to Persons

Seven passengers and one flight attendant reported injuries that were classified as minor, and no one was transported to a hospital.[14] Passenger-reported injuries included bruises and neck or ear pain, and flight attendant D reported receiving bruises on her right arm and knee from being struck by the flight deck door. None of the three lap-held children on board the airplane sustained injury.

1.3 Damage to Airplane

Examination of the airplane revealed a hole in the left fuselage next to seating row 26 where the left MED plug was missing. Damage was observed on various components on the fuselage frame that surrounded the hole, including fittings and assemblies associated with the left MED plug installation. Interior sidewall panels were missing, and insulation was exposed on both sides of the opening where the left MED plug had been (see figure 1).

[14] Alaska Airlines reported that two additional passengers independently sought medical observation for a chronic medical condition and examination at local medical facilities and were released the same day without documented injuries.

Figure 1. Interior view showing hole in left fuselage at row 26.

The seat unit 26ABC frame was structurally intact and undamaged. It was connected firmly to the floor with spacers in place between rows 25 and 26. The seatback for seat 26A (the seat closest to the fuselage hole) was deformed forward and outboard, the outboard armrest was deformed outboard, the supports for the seatback tray table (facing seat 27A) were fractured, and the seatback tray table, support pieces, seatback cushion, and headrest were missing. Three of the four oxygen masks (with their respective reservoir bags) that had deployed above seat unit 26ABC were missing. The reservoir bag for the remaining mask was shredded.

The seat unit 25ABC frame was structurally intact and undamaged. It was connected firmly to the floor with spacers in place between rows 24 and 25. The seatback for seat 25A was deformed outboard and aft, the seats 25A and 25A headrests were missing (see figure 1), and the seat 25A bottom cushion was displaced upward.

Other damage observed in the cabin included buckling and displacement of interior sidewall panels and trim in numerous areas from rows 1 through 27, and deformation of the doorframe of the forward lavatory.

The missing left MED plug, seat 26A seatback tray table, seat 25A headrest, and pieces of interior sidewall were located on the ground (along the airplane's flight path) and recovered. The left MED plug was recovered largely intact and sustained damage to the plug structure and various attachments and fittings.[15] Multiple components associated with the left MED plug installation, including four bolts that would secure the left MED plug from moving vertically, were not located.

The NTSB Materials Laboratory examined the left MED plug and various components associated with its installation (see sections 1.5.2 for more information about the design of an MED plug structure and associated components and 1.10.1.1 for more information about the examinations of the damage on the accident airplane's left MED plug structure and associated components).

1.4 Personnel Information

1.4.1 Captain

The captain, age 48, held an airline transport pilot certificate with B-737 and EMB-120 type ratings.[16] The certificate had a limitation specifying visual weather conditions only for circling approaches in the B-737. He held a first-class medical certificate issued September 8, 2023, with no limitations.

The captain had been employed at Alaska Airlines since August 2007. He reported about 12,700 hours of total flight experience, including about 6,500 hours in Boeing 737 airplanes. According to Alaska Airlines, at the time of the accident, the captain had 304 hours experience in the Boeing 737-9.

Alaska Airlines' training records for the captain included the events shown in table 1.

Table 1. Captain's training events.

Training event	Completion date
Basic indoctrination for flight personnel	August 30, 2007
First officer initial (Boeing 737 NG)	November 16, 2007
Captain upgrade (Boeing 737 NG)	November 17, 2018
Initial Boeing 737-9 familiarization computer-based training	December 17, 2020
Initial Boeing 737-9 familiarization simulator	January 6, 2021
Most recent line check (Boeing 737 NG)	February 1, 2023
Continuing qualification Boeing 737 evaluation period	April 7, 2023
Continuing qualification quarterly training	July 24, 2023

[15] The damage, which adversely affected the pressurization performance of the airplane and the structural strength of the MED plug (requiring replacement), met the substantial damage classification criteria specified in 49 *CFR* Part 830.2 that defined this event as an aircraft accident.

[16] The B-737 type rating included The Boeing Company 737-300, 737-400, 737-500, 737-600, 737-700, 737-700C, 737-800, 737-900, 737-900ER, 737-8, and 737-9 airplanes. The EMB-120 type rating included various Embraer S.A. EMB-120-series airplanes (FAA 2024a). The captain also held a flight instructor certificate for single-engine, multiengine, and instrument airplanes.

The captain's most recent rapid depressurization simulator scenario was completed October 2, 2007, during his first officer initial qualification training in the Boeing 737 NG. His initial Boeing 737-9 familiarization computer-based training included a module on oxygen mask and communications differences.

The captain's training records indicated that he received hands-on oxygen mask training during continuing qualification simulator events. The most recent training occurred during a continuing qualification simulator event in 2023 (see section 1.11.1.1 for more information).

1.4.2 First Officer

The first officer, age 36, held an airline transport pilot certificate with B-737, A320, CL-65, EMB-145, and CE-500 type ratings.[17] The certificate specified limitations for visual weather conditions only for circling approaches in the B-737, A320, and CL-65, and a requirement for a second-in-command pilot in the CE-500.

She had been employed at Alaska Airlines since August 2017. She reported about 8,300 hours of total flight experience, including about 1,500 hours in Boeing 737 airplanes. According to Alaska Airlines, at the time of the accident, the first officer had 311 hours experience in the Boeing 737-9.

Alaska Airlines' training records for the first officer included the events shown in table 2.

Table 2. First officer's training events.

Training event	Completion date
Initial Boeing 737-9 familiarization computer-based training	September 1, 2021
Initial Boeing 737-9 familiarization simulator	September 7, 2021
Boeing 737 first officer transition	September 22, 2021
Most recent line check (Boeing 737 NG)	June 5, 2023
Continuing qualification quarterly training	July 10, 2023

The first officer's most recent rapid depressurization simulator scenario was completed August 12, 2021, during her first officer transition qualification training. Her initial Boeing 737-9 familiarization computer-based training included a module on oxygen mask and communications differences.

[17] The A320 type rating included Airbus SAS A318, A319, A320, and A321 airplanes. The CL-65 type rating included various Bombardier Inc. CL-600-series airplanes, the EMB-145 included various Embraer S.A. EMB-135 and 145-series airplanes, and the CE-500 included Textron Aviation Inc. 500, 501, 550, S550, 551, 552, and 560 airplanes (FAA 2024a). The first officer also held a flight instructor certificate for single-engine, multiengine, and instrument airplanes and an advanced ground instructor certificate.

Based on the first officer's training records, her most recent hands-on oxygen mask training occurred during a continuing qualification simulator event in 2023 (see section 1.11.1.1 for more information).

1.4.3 Flight Attendants

Alaska Airlines' records for each flight attendant reflected the training dates shown in table 3.

Table 3. Flight attendants' training event completion dates.

Flight attendant position	New hire training	Boeing 737-9 differences training	Most recent annual recurrent training
A	May 2019	April 2019	May 2023
B	August 2005	April 2019	September 2023
C	June 2017	April 2019	May 2023
D	August 2015	April 2019	July 2023

Note: Flight attendant A received differences training as part of his new hire training.

1.5 Airplane Information

1.5.1 General

The Boeing 737-9 is a twin-engine, narrow-body, transport-category airplane originally certificated in 2018; per its type certificate, it is operated by a minimum crew of two pilots. It is powered by two CFM International LEAP-1B28 engines, each capable of producing 29,317 lbs of thrust, and is part of the Boeing 737 MAX family of airplanes. The airplane is 138 ft long and 41 ft tall, with a 12-ft fuselage diameter and a 118-ft wingspan (rounded to the nearest foot). The wing, fuselage, and tail primary and secondary structures are of all-metal construction, primarily aluminum alloy.

The accident airplane was configured with two crew seats, two flight deck jump seats, three dual-position flight attendant jump seats, and 178 passenger seats. Weight and balance calculations completed for the accident flight showed that the airplane was within applicable limits at takeoff and landing.

Per design, the Boeing 737-9 is equipped with a rectangular opening on each side of the fuselage aft of the wing that can accommodate the installation of an emergency exit door when required for certain passenger seating configurations. For configurations (like the accident airplane's configuration) that did not require an emergency exit door at that location, an MED plug can be installed as a lower weight, less complex option.[18] The accident airplane was equipped with two MED plugs, one each on the left and right sides of the fuselage (see figure 2).

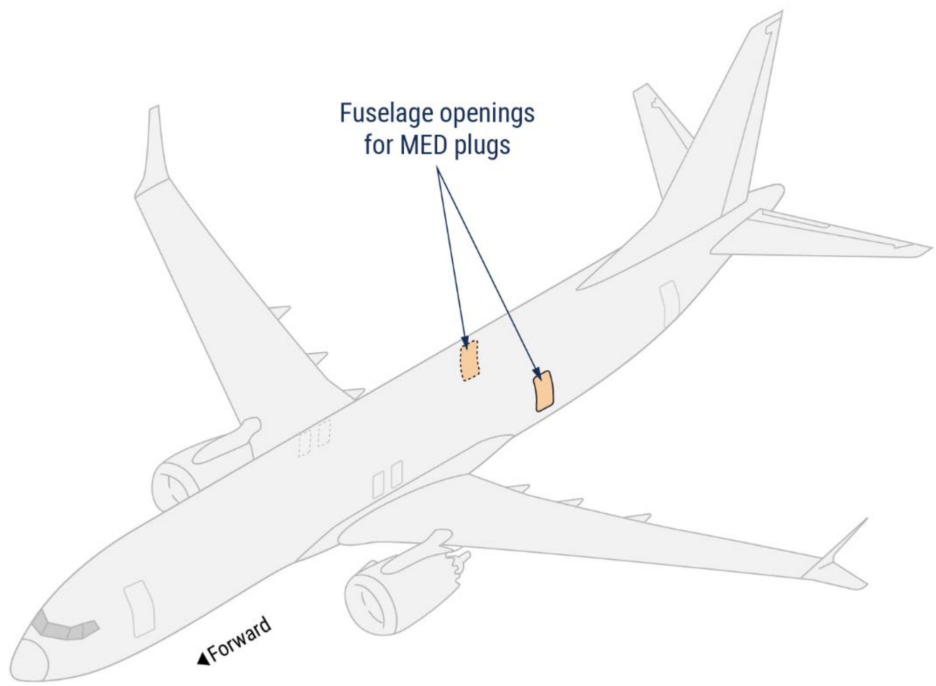


Figure 2. Locations of fuselage openings for MED plug installations.

Alaska Airlines took delivery of the accident airplane from Boeing on October 31, 2023, and placed it into service on November 11, 2023. At the time of the accident, the airplane had accumulated 510 hours and 154 cycles.

The NTSB's review of Alaska Airlines' maintenance records revealed no record of any maintenance, inspection, or retrofit work performed since airplane delivery that would require opening the left MED plug.

The maintenance log books for the airplane documented the illumination of the cabin pressurization AUTO FAIL light during flights on December 7, 2023; January 3, 2024; and January 4, 2024.[19] The records documented the maintenance

[18] An emergency exit door installed at that location would weigh more than an MED plug and be equipped with, at a minimum, door actuation mechanisms, a pressure relief vent panel, and a viewport (which differs from a full-size passenger cabin window).

[19] The AUTO FAIL light will illuminate due to such events as the failure of a cabin pressure controller; power loss; excessive cabin altitude or cabin altitude change rate (and the outflow valve is not in the correct position); or failures with the selector panel, wiring, or outflow valve components. According to the captain of the accident flight, he was aware of previous write-ups about the AUTO FAIL light illuminations and discussed them with the first officer during the departure briefing.

activity Alaska Airlines performed in response to each event, including a January 4, 2024, request for additional maintenance troubleshooting of the repetitive defect.[20] In addition, the airline restricted the airplane from certain extended range operations so that it would remain near maintenance bases should another AUTO FAIL light illumination event occur.[21]

See section 1.10.2 for information about the NTSB's examination of the accident airplane's cabin pressurization system, including the previous AUTO FAIL light illumination events.

1.5.2 Mid Exit Door Plug Structure

An MED plug is a principal structural element made primarily of aluminum alloy and certified in accordance with damage-tolerance and fatigue evaluations criteria specified in 14 *CFR* 25.571. An MED plug is equipped with two upper guide fittings (near the top of the plug) and two lower hinge guide fittings (near the bottom of the plug).

As properly installed, an MED plug's upper guide fittings are engaged with upper guide rollers on the fuselage frame, and the plug's lower hinge guide fittings are engaged with lower hinge fittings at the lower hinge bracket assemblies on the fuselage frame (see figure 3). By design, an MED plug can be opened for airplane maintenance and inspection purposes, by first removing four bolts that secure it from moving upward vertically (discussed in more detail later in this section). The four bolts that secure an MED plug from moving upward vertically are installed in the following locations:

- One upper guide track bolt is installed through each upper guide fitting below the upper guide roller. Each bolt installation (with two washers) is secured with a castle nut and cotter pin.
- One vertical movement arrestor bolt is installed in each lower hinge guide fitting on the lower hinge assembly, such that the bolt would also pass through the hinge fitting shaft. Each bolt installation (with two washers) is secured with a castle nut and cotter pin.

The MED plug is also equipped with 12 stop fittings (6 on each vertical side) such that, in the plug's installed position, the plug's stop fittings align inboard of

[20] Per Alaska Airlines' maintenance policy, if a defect is reported two times in 10 days, the discrepancy must be evaluated by technical services.

[21] At the time of the accident, the airplane was also restricted from extended range operations due to the deferral of an aft fuel boost pump per Alaska Airlines' minimum equipment list for the airplane.

corresponding stop fittings on the fuselage frame and prevent the plug from moving outboard. Each plug stop fitting has a stop pin that abuts the face of the stop pad on each corresponding fuselage frame stop fitting.

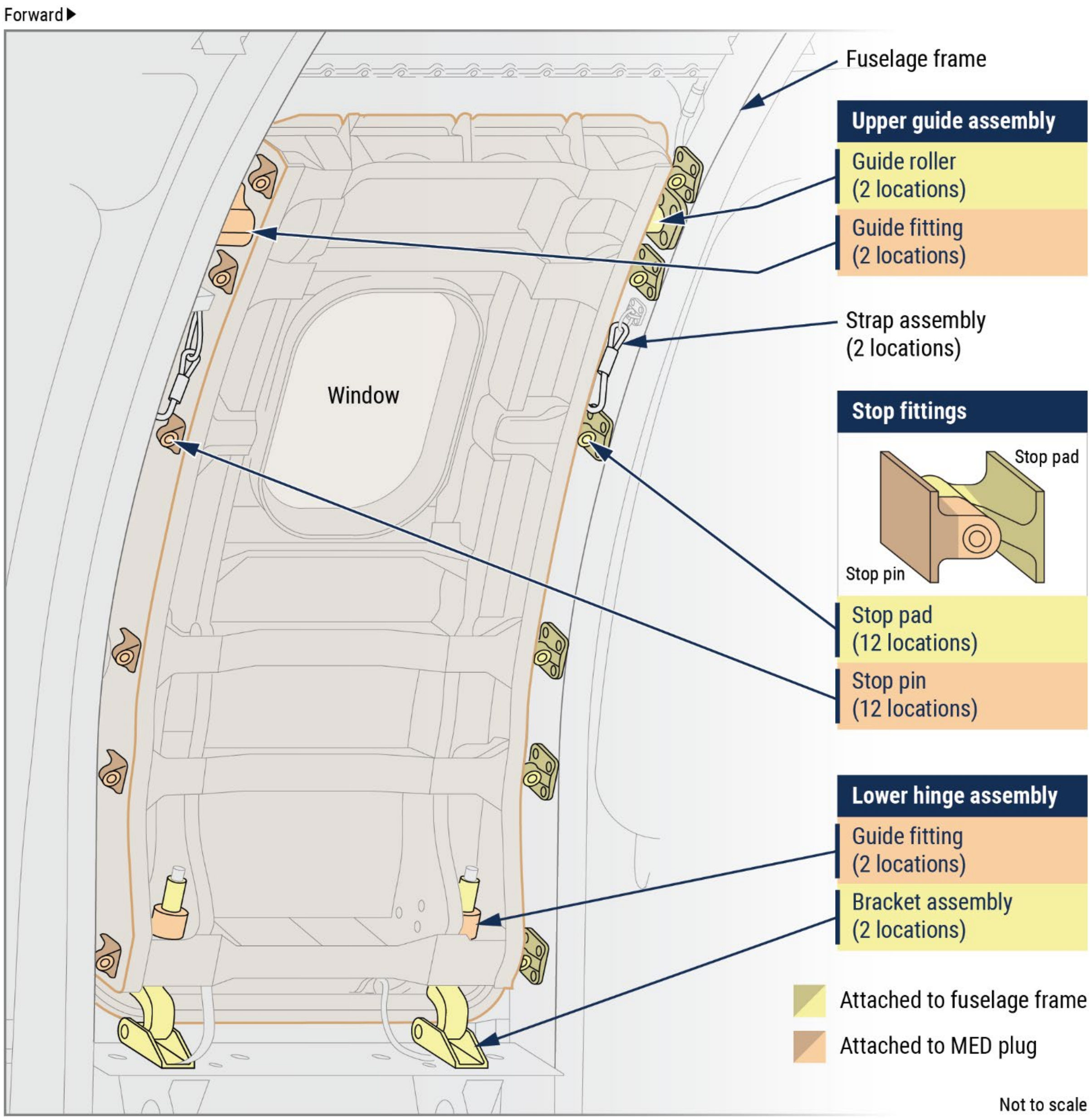


Figure 3. Conceptual diagram of the left MED plug installation. (Source: Adapted from a Boeing diagram.)

Note: Six fuselage frame stop fittings, six plug stop fittings, and one upper guide fitting are not depicted to show detail of the adjacent or underlying components. Also, the vertical movement arrestor bolts and upper guide track bolts are not visible in this diagram.

The accident airplane's MED plugs were each equipped with a full-size passenger window. When viewed from the exterior, the outline of each plug was visibly discernable (see the left side of figure 14 in section 1.10.1.2). When viewed from the interior, cabin sidewall panels installed at the MED plug locations were visually similar to other interior panels throughout the cabin such that no MED plug outline was visible.[22]

As stated previously, by design, an MED plug can be opened for airplane maintenance and inspection purposes. Access to the MED plug attachment hardware on an in-service airplane requires the removal of interior panels (and underlying insulation), and opening the MED plug requires the use of tools to remove the cotter pins, nuts, and upper guide track bolts and vertical movement arrestor bolts. Once the bolts are removed, the plug can be moved vertically upward to allow its upper guide fittings to clear the upper guide rollers and its stop fittings to clear the frame's stop fittings (see figure 4 and figure 5). (Two lift assist springs, one in each lower hinge assembly, assist in keeping the plug raised while clearing the stops. Each spring provides about 50 lbs of force when fully compressed.)

[22] The only visible difference with the rest of the cabin was a slight difference in the passenger window spacing between the MED plug window and the row of windows installed both forward and aft of it.

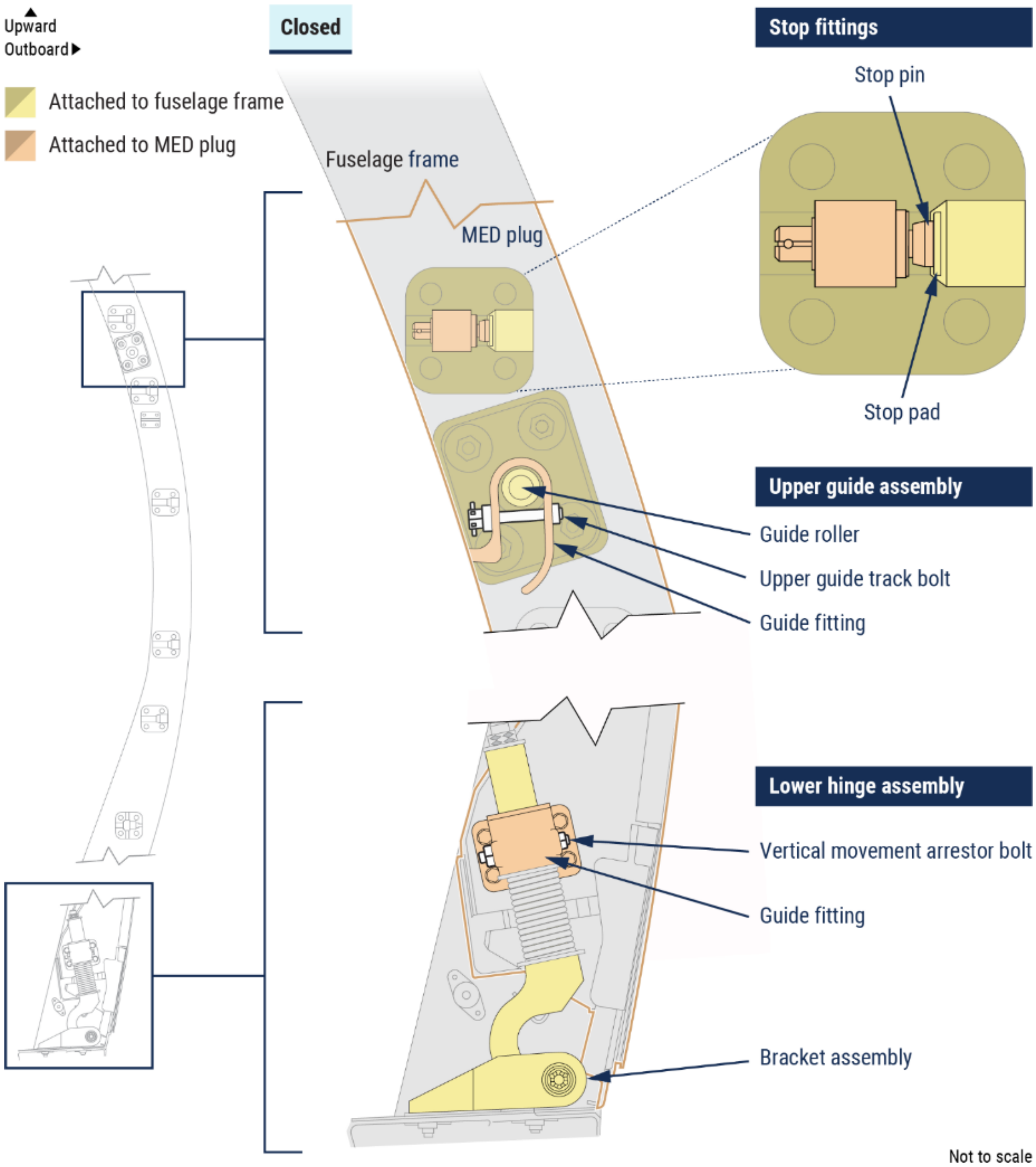


Figure 4. Conceptual diagram of the side view of an MED plug installation. (Source: Adapted from a Boeing diagram.)

Note: This diagram shows the location of an upper guide track bolt installed through an upper guide fitting below an upper guide roller; the location of a vertical movement arrestor bolt installed through the lower hinge guide fitting and hinge fitting shaft; and the alignment of the plug stop fitting stop pins inboard of the fuselage frame stop pads.

Once the plug is moved sufficiently upward for the upper guide fittings to clear the upper guide rollers, the top of the plug can be pushed outboard to open it. At the point where the plug's upper guide fittings clear the upper guide rollers, the plug's stop fittings have cleared the stop pads by about half an inch (see figure 5).

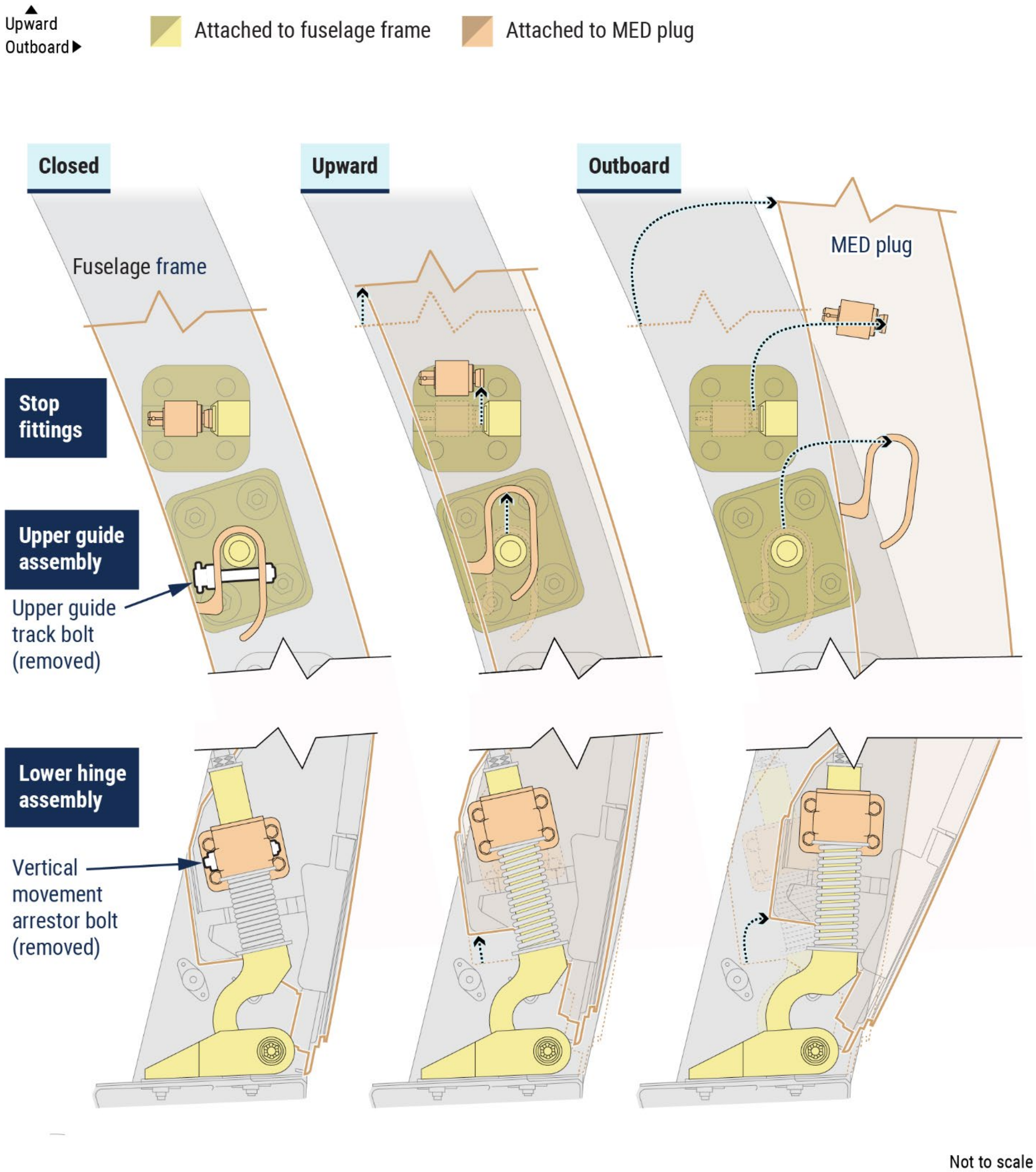


Figure 5. Conceptual diagram showing side views of the alignment of components for an MED plug in three positions. (Source: Adapted from a Boeing diagram.)

Note: The MED plug positions shown are closed (left), displaced upward (center), and opened outboard (right). Dashed lines with arrows exaggerate the amout of upward displacement necessary for the plug's stop fittings (with stop pins) to clear the fuselage frame's stop fittings (with stop pads) before the plug can be opened outboard.

When the top of the plug is pushed open, the bottom of the plug rotates outward around the lower hinge fitting pivot. The plug is equipped with strap assemblies that prevent the plug from opening more than 15°, when opened during maintenance, as needed (see figure 6).

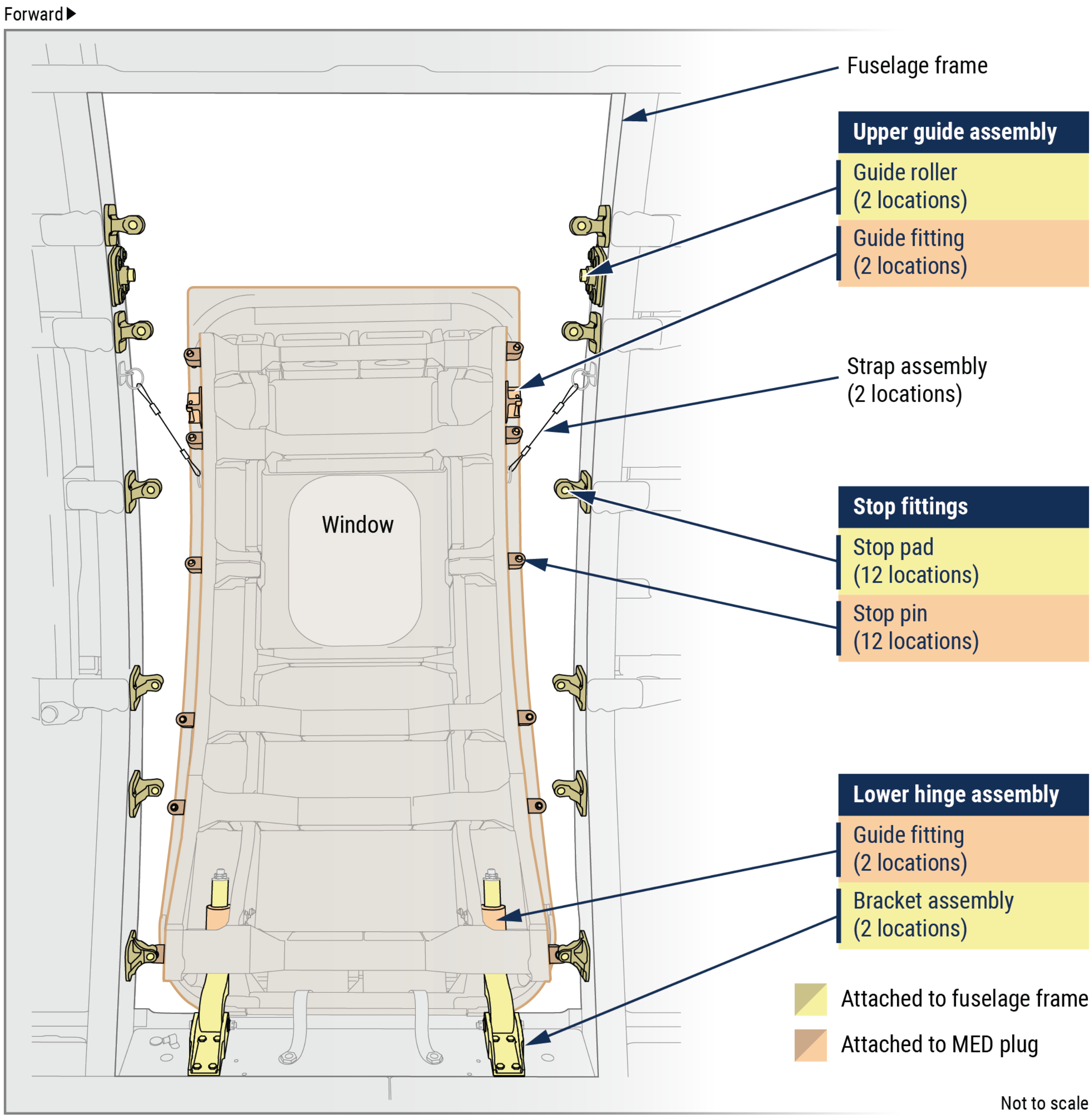


Figure 6. Conceptual diagram of MED plug in open position. (Source: Adapted from a Boeing diagram.

1.5.3 Cabin Pressure Control and Supplemental Oxygen Equipment

The airplane's cabin pressurization system was designed to maintain a safe, comfortable cabin pressure altitude at all times and, under normal operations, the maximum cabin pressure altitude is about 8,000 ft. Air conditioning packs continuously force air into the airplane pressure vessel (which includes the cabin and flight deck), and the cabin pressurization control system adjusts the position of the outflow valve gates, which changes the rate of air released from the cabin. A flight crew can control cabin pressure using one of three modes: automatic, alternate, and manual.

The cabin pressurization control system uses two identical cabin pressure controllers (CPCs), with one CPC identified as the CPC-in-command, and the other identified as the alternate, or backup. (The CPC-in-command alternates each flight leg.)

In the automatic pressurization control modes (automatic and alternate), cabin pressurization is automatically scheduled for all phases of the flight.[23] The CPC-in-command compares the target pressure to the pressure at its internal sensor, and, if there is a difference, the CPC sends an open or close command to the outflow valve assembly. If the CPC-in-command fails, the system automatically changes pressurization control to the alternate CPC. In the event that both CPCs fail, the pilots can use manual mode to manually control the outflow valve.[24]

A cabin altitude warning system alerts the flight crew (with an aural horn and warning lights) when the cabin pressure altitude exceeds 10,000 ft. (Per design, it is acceptable for this system to activate anywhere between 9,000 and 11,000 ft.) Also, as discussed in section 1.5.1, a cabin pressure AUTO FAIL light will illuminate to alert the flight crew of certain anomalous conditions involving the cabin pressure control system, such as the failure of a CPC. In addition, the flight deck door is designed to open to relieve pressure in the flight deck during a significant sudden cabin depressurization event. (The use of the flight deck door as a pressure relief device in the event of a rapid depressurization is an accepted industry design practice. Other Boeing airplanes that have flight deck doors with similar functionality include the Boeing 747, 767, 777, and 787.)

---

[23] The automatic pressurization schedule is calculated based on the flight altitude and landing altitude, which is set by the flight crew before departure.

[24] Other components related to the cabin pressurization system include positive pressure relief valves, a negative pressure relief valve, and blowout panels, all designed to protect the airplane structure from excessive pressure differentials.

1.5.3.1 Flight Crew Emergency Oxygen Equipment

The airplane was equipped with B/E Aerospace full-face, sweep-on oxygen masks (one in each stowage box in the captain and first officer's side consoles and one at each observer's position) designed to provide both respiratory and visual protection. Designed to be donned and functioning in less than 5 seconds using only one hand, each mask has an inflatable harness connected to the regulator and face shield.

The mask design allows flight crews to select the oxygen delivery appropriate for the type of emergency. The face shield allows oxygen to enter the face shield for purging of smoke and fumes and has a dynamic microphone to provide a means of communication via the aircraft audio communication system.

The system is designed for the mask to automatically provide oxygen flow and mask microphone selection when the stowage box right door is opened during mask removal from the stowage box. (A flow indicator displays a yellow cross to indicate that oxygen is flowing to the mask, and an OXY ON flag appears to indicate that the oxygen shutoff valve is open.) Closing the stowage box right door and pushing the RESET/TEST switch on the stowage box door shuts off the flow of oxygen and deactivates the mask microphone (see figures 7 and 8).[25]

[25] Each crewmember's oxygen mask stowage box was equipped with an oxygen mask RESET/TEST switch (spring loaded to the RESET position) designed to enable crews to momentarily test the operation of the regulator when the right stowage box door is closed.

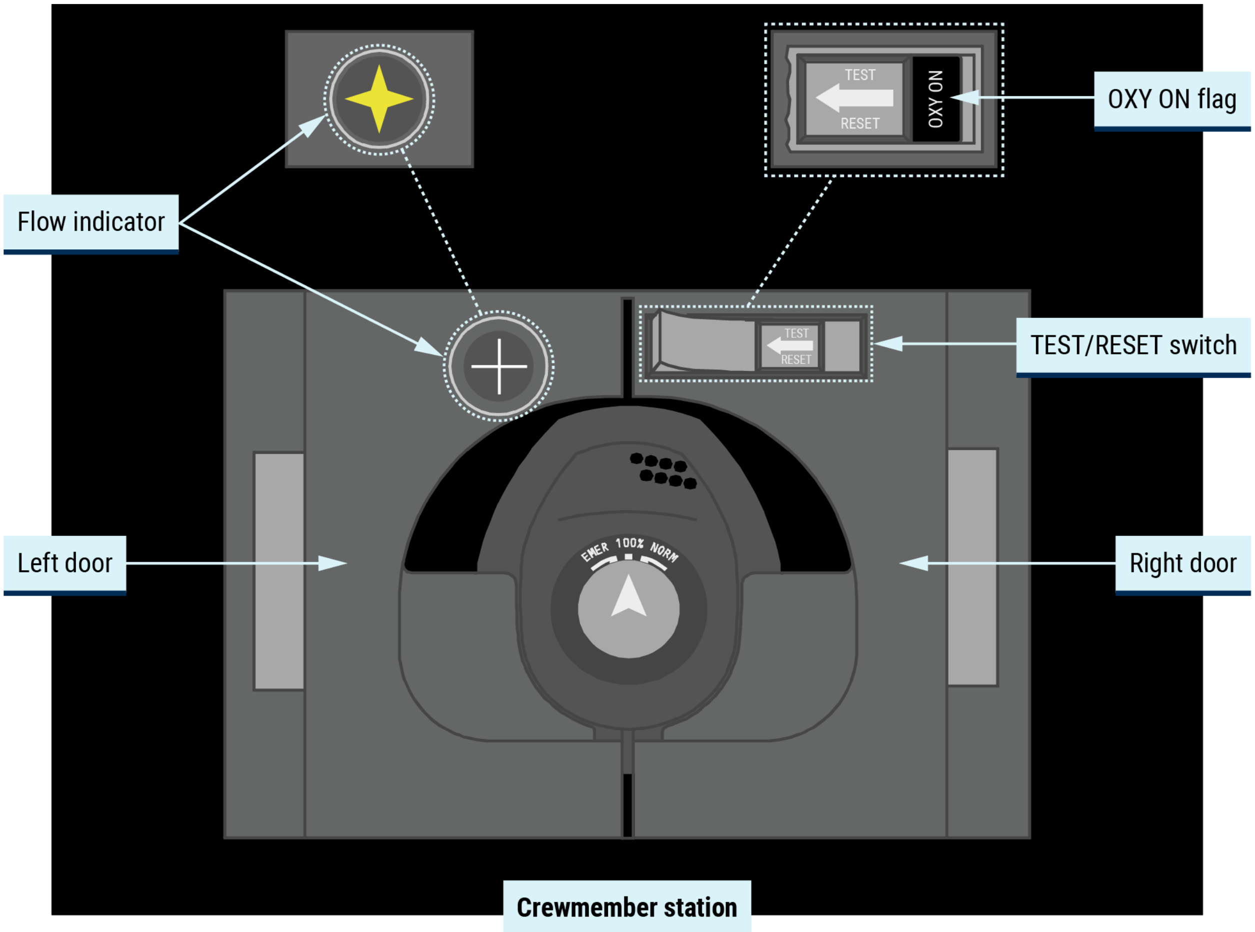


Figure 7. Oxygen mask stowage box. (Source: Adapted from the Alaska Airlines Boeing 737 Systems Handbook)

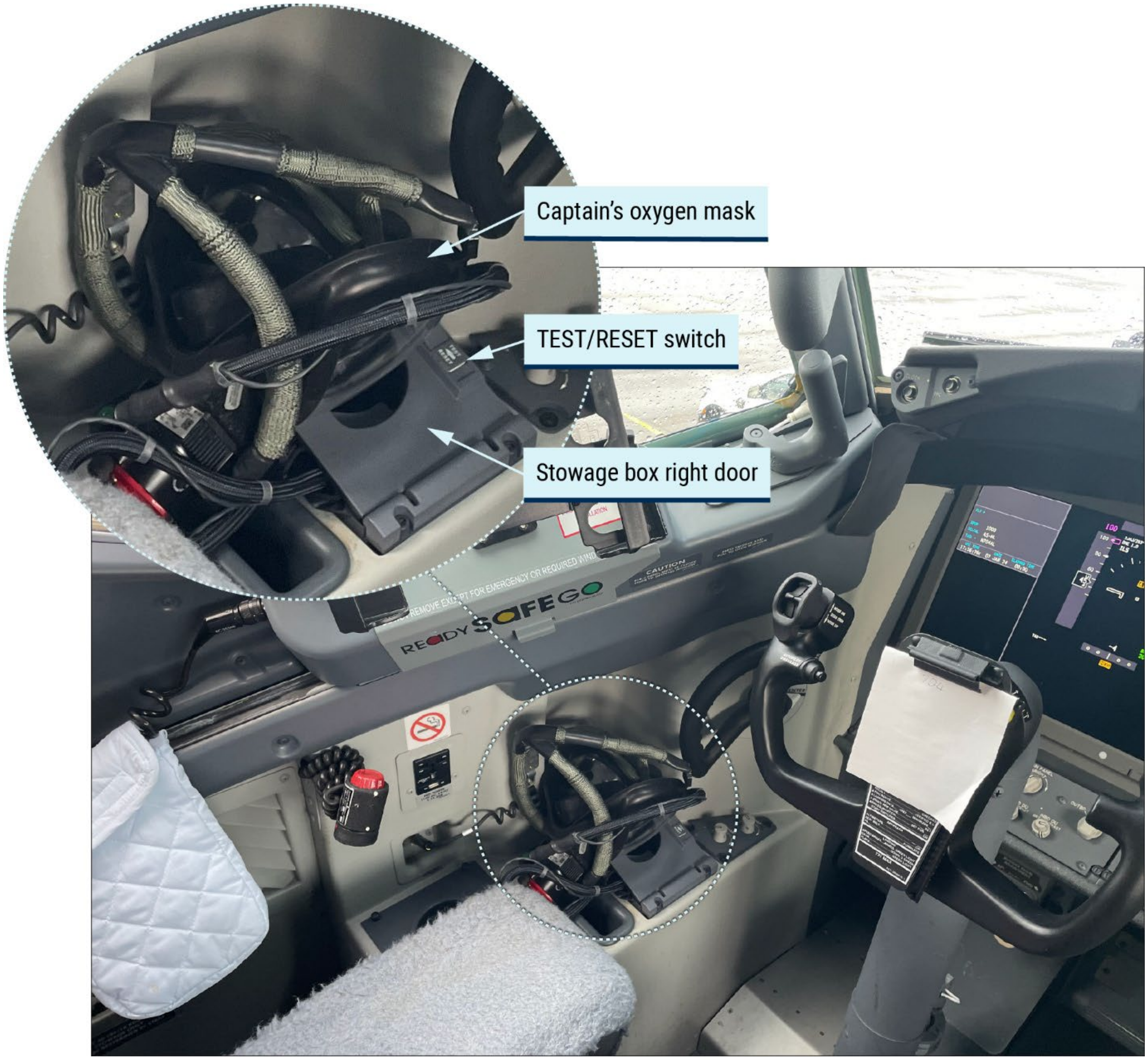


Figure 8. Captain's oxygen mask stowage box, showing mask unstowed and right door partially open.

1.5.3.2 Cabin Emergency Oxygen Equipment

The airplane was equipped with a supplemental oxygen system that provided multiple oxygen masks at each passenger seat unit, flight attendant jump seat, and lavatory. The system provided four masks at each passenger seat unit (ensuring extra mask availability for lap-held children or flight attendants passing through the cabin) and two masks at each flight attendant station and lavatory.[26]

Each passenger service unit contained mask assemblies that were stowed in an overhead compartment. By design, the system automatically would activate at a cabin pressure altitude of about 14,000 ft, opening the service unit doors and allowing the masks to drop down.[27] In the passenger cabin, the masks would drop down from above the outboard (window) seat at each seat unit and remain suspended from above (by their plastic tubes) until pulled down by a user (see figure 9).

Figure 9. Photograph showing the passenger service unit doors open above the outboard (window) seats on the right side of the airplane.

Note: The tubing for the four deployed oxygen masks is visible.

[26] Each mask had a cup-style face piece to cover the user's nose and mouth and an elastic band to secure the mask in place. A passenger seat unit was composed of two or three seats, one on each side of the aisle. (For example, row 26 was composed of seat units 26ABC and 26DEF; see section 1.9.) Per 14 *CFR* 25.1447, airplanes (like the accident airplane) certificated for altitudes higher than 25,000 ft were required to have at least 10 percent more oxygen masks in the cabin than seats.

[27] The pilots also had a switch on the flight deck that enabled them to manually activate the system, if needed.

For each passenger service unit, the action of pulling a mask down created oxygen that flowed to the masks attached to that unit. For each flight attendant station, pulling a tab that dropped with the masks activated the flow of oxygen.

The airplane was also equipped with portable oxygen bottles stowed in forward, middle, and aft cabin locations, including two bottles stowed in a cabinet near door L1 and two stowed in a compartment above seat unit 32ABC. (Flight attendants on the accident flight retrieved one bottle from each of these locations. See section 1.9.) Each pressurized bottle was equipped with a valve to start the flow of oxygen, folded mask and tubing stowed inside an attached pouch, a shoulder strap, and an extra mask in an attached pouch.

1.6 Meteorological Information

PDX airport had an automated surface observing system that was augmented by contract weather observers. At 1653, the reported weather conditions included wind from 180° at 11 kts, visibility 10 miles, ceiling overcast at 6,000 ft agl, temperature 10°C, dew point 4°C, and altimeter setting of 30.23 inches of mercury.

1.7 Airport Information

PDX was a joint civil-military airport located within the city limits of Portland. The airport elevation was 31 ft msl with three paved airplane landing surfaces designated as runways 28L/10R, 28R/10L, and 21/3. The paved surface for runway 28L/10R was 11,000 ft long and 150 ft wide, 28R/10L was 9,825 ft long and 150 ft wide, and 21/3 was 6,000 ft and 150 ft wide. The airport was serviced by an air traffic control tower, which was in operation at the time of the accident.

1.8 Flight Recorders

1.8.1 Cockpit Voice Recorder

The airplane was equipped with an L3Harris FA2100 CVR designed to record a minimum of 120 minutes of digital audio stored on solid-state memory modules.[28] Examination of the CVR identified no heat or structural damage, and the audio information was extracted normally.

[28] The airplane, based on its operation under Part 121, was required to be equipped with a CVR that records, at minimum, the last 2 hours of aircraft operation. By design, the CVR starts recording when the aircraft is powered on and continues to record until the aircraft is powered down or the CVR is deactivated, by either a loss of electrical power or manual deactivation of the CVR's circuit breaker.

The recovered audio began at 1831:29, which was about 1 hour 20 minutes after the in-flight MED plug separation (and more than an hour after the accident flight landed). Alaska Airlines' flight operations manual specified that flight crews involved in an incident or accident were required, if possible, to pull the CVR and FDR circuit breakers as soon as possible after the airplane is secured; however, this did not occur following the accident. By the time maintenance personnel responded to the airplane to pull the CVR circuit breaker, the audio for the accident flight had been overwritten.

1.8.2 Flight Data Recorder

The airplane was equipped with an L-3/Fairchild FA2100 FDR capable of recording a minimum of 25 hours of flight data in a digital format using solid-state flash memory as the recording medium.[29] The recorder was in good condition, and about 68.25 hours of data, including data for the accident flight, were extracted normally.

The airplane was also equipped with a quick access recorder (QAR), a type of recorder typically used by operators to provide flight data to support flight data monitoring or flight operations quality assurance programs.[30] The QAR provided about 31.75 hours of data, including the accident flight and the eight previous flights.

1.9 Survival Aspects

The accident airplane's cabin was equipped with 178 passenger seats divided into Alaska Airlines' first class, premium, and economy sections. Rows 1–4 (first class) consisted of 16 seats in an AC DF configuration, rows 6–9 (premium) consisted of 24 seats in an ABC DEF configuration, and rows 10–13 and 15–34 (economy) consisted of 138 seats in an ABC DEF configuration, except for rows 33 and 34, which had only DEF seats.[31]

The airplane had four type C floor-level emergency exits (forward cabin doors L1 and R1 and aft cabin doors L2 and R2) and four type III emergency exits located at

[29] The airplane was required to be equipped with an FDR, per 14 *CFR* 121.344(f), which specified the requirement for turbine-engine-powered, transport-category airplanes manufactured after August 19, 2002, and operated under Part 121.

[30] QARs are not subject to FAA requirements for equipage (such as by aircraft type, date of manufacture, or operation) or crash protection.

[31] The airplane was configured without a row 14.

rows 16 and 17 (two overwing exits on each side of the airplane).[32] Three aft-facing, dual-position flight attendant jump seats were located (one each) at doors L1, L2, and R2.

According to the passenger list for the accident flight, three lap-held children were seated with caregivers in seats 19D, 31E, and 32D.[33] Four unaccompanied minors were also on the flight: a 6-year-old seated in 32C, an 11-year-old seated in 7F, and siblings ages 12 and 17 seated in 32A and 32B, respectively.[34] Ten seats (seat 10A, 10E, 16D, 16E, 17B, 23E, 26A, 26B, 26F, and 28B) were vacant.[35]

As described in section 1.1, after the depressurization event, all four flight attendants immediately donned oxygen masks that deployed from above their jump seats. All flight attendants stated they felt oxygen flowing to their mask.

Postaccident interviews revealed that none of the caregivers of the lap-held children on the accident flight reported difficulty retrieving or donning an oxygen mask for themselves, retrieving an oxygen mask for their lap-held child, or holding onto their child. One caregiver reported that his 9-month-old daughter would not allow him to put her mask on, so he held the mask in front of the child's face. Another caregiver stated that she did not use the elastic band for her 1-year-old son, as he would not allow it to be placed around his head, so she kept the mask over his face. No passenger reported difficulty retrieving or donning an oxygen mask.

Portable oxygen bottles (each equipped with a shoulder strap) were available to flight attendants so that they could move about the cabin and stay on oxygen, if needed. Flight attendant D used a portable oxygen bottle (one of two available in a stowage compartment near her jump seat) to check on the unaccompanied minor in seat 7F and to assess why passengers were standing in the aisle and not heeding her commands to return to their seats. Flight attendant D stated she had difficulty removing the mask from its plastic packaging and recalled using her identification badge to puncture the plastic pouch to open it. She eventually removed the mask but

---

[32] Per 14 *CFR* 25.807, a type C exit is a floor-level exit with a rectangular opening at least 30 inches wide by 48 inches high, and a type III exit is a rectangular opening at least 20 inches wide by 36 inches high. A type III exit has a maximum step-up inside the airplane of 20 inches, and, if located over the wing, a maximum step-down outside the airplane of 27 inches.

[33] Per the Alaska Airlines FAM, only one lap-held child was allowed per full row.

[34] A maximum of six unaccompanied minors were permitted on any single flight per Alaska Airlines policy. The preferred seating location for unaccompanied minors was in the last full row or near flight attendant jump seats and galleys, but they could be seated elsewhere in the cabin when needed. Flight attendant briefings for unaccompanied minors included seat belt and oxygen mask usage (among other topics).

[35] According to Alaska Airlines' records, two individuals had checked in for seats 26A and 26B on the accident flight but were late arriving to the airport and were rebooked onto a later flight.

then encountered difficulty unfolding and opening it. She quickly abandoned her attempt to properly attach it over her nose and mouth with the elastic band around her head. Instead, she held the mask over her mouth and nose while walking aft to check on passengers, using the shoulder strap to carry the bottle.

Flight attendant B, who also used a portable oxygen bottle (one of two available in a stowage compartment above seat unit 32ABC), said it was “awkward” to remove the mask from its packaging and to uncoil the tubing. He had difficulty donning the mask over his head and glasses and attaching in place over his nose and mouth but was eventually able to do so.

When flight attendant C moved forward through the cabin to check on the youngest unaccompanied minor in seat 32C, she used the mask-to-mask procedure (breathing by using the extra oxygen masks hanging from the passenger service units in the cabin) as described in Alaska Airlines’ procedures (see section 1.11.1.2). She said the procedure was challenging because passengers did not understand that she needed them to hand her a spare mask (she could not reach the masks that were not in use at each row, as they were located too far outboard, as seen in figure 9), and some masks were entangled. She found the unaccompanied minor in seat 32C with his mask on but not tight around the face. She tightened his straps and returned to the aft cabin.

As stated in section 1.1, passengers reported that, during the rapid depressurization, the 15-year-old boy who was initially seated in seat 25A had his shirt pulled off his body. Some passengers reported that they heard that the passenger who remained in seat 26C lost his laptop computer, car keys, and cell phone out the hole and that the passenger in seat 27A lost both shoes and his left sock.

1.10 Tests and Research

1.10.1 Mid Exit Door Plugs

1.10.1.1 Left Mid Exit Door Plug and Associated Components

Investigators in the NTSB Materials Laboratory examined the recovered left MED plug and associated components that were removed from the airframe to facilitate laboratory examination, including all 12 frame stop fittings (with stop pads), both upper guide rollers, both lower hinge assemblies, and the aft lower hinge guide fitting.

Multiple components were missing and not recovered, including the two vertical movement arrestor bolts and two upper guide track bolts (and associated washers, castle nut, and cotter pin for each). Also, the forward lower hinge guide fitting flange was fractured, and the lift assist spring, washers, and pieces of guide fitting were missing (see figure 10).

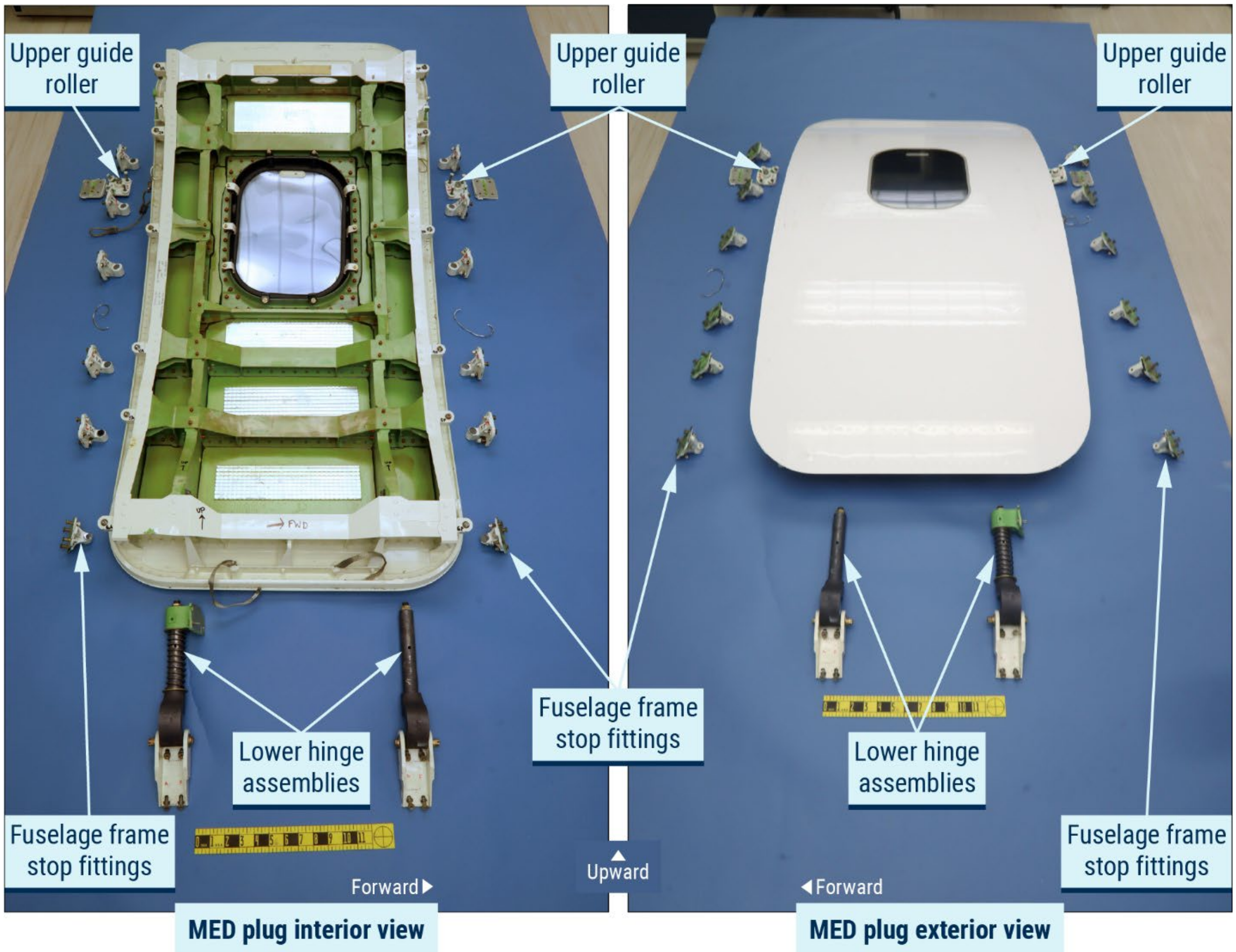


Figure 10. Photographs of the left MED plug and associated components showing an interior view (left) and exterior view (right).

The left MED plug was mostly intact with some damage from the event. All 12 plug stop fittings and all 12 stop pads (on the corresponding fuselage frame stop fittings) were intact. A series of parallel dark lines on the upper inboard side were identified as an accumulation of dust, dirt, and petroleum jelly.[36]

Six of the stop pins (on the plug stop fittings) were damaged with missing heads. Sliding contact marks were noted on the lower sides of the 12 stop pins and

[36] The investigation identified that Spirit AeroSystems installation personnel used petroleum jelly to lubricate MED plug seals during installation, which was not consistent with Boeing specifications. See section 1.12.3.1 for more information.

plug stop fittings. Corresponding contact damage was noted on the upper sides of the 12 frame stop fittings. The orientation and geometry of the sliding contact marks and damage on the frame stop fittings and plug stop fittings mostly exhibited features consistent with the plug displacing upward before clearing the stop fittings then displacing outboard and aft (see figure 11).

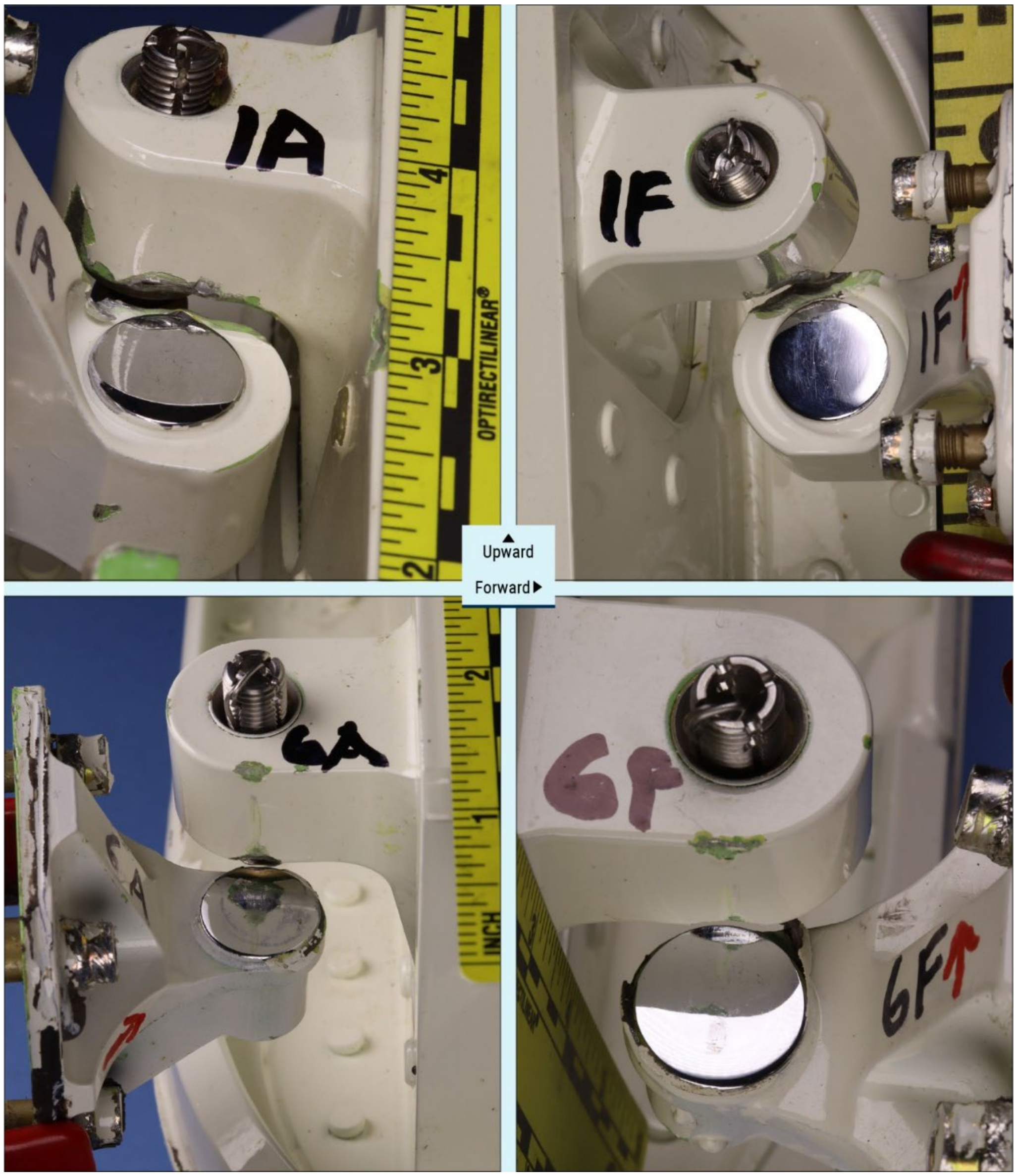


Figure 11. Views of four frame stop fittings placed next to their corresponding plug stop fittings. (Marker labels and arrows added during the examination.)

Note: Corresponding sliding contact damage is shown for each frame stop fitting (with stop pad) and plug stop fitting pair. The displayed fittings are from the left MED plug's upper aft (labeled 1A), upper forward (1F), lower aft (6A), and lower forward (6F) locations and corresponding frame locations.

The upper guide rollers were intact. The left MED plug's forward and aft upper guide fittings each had a vertical fracture through the inboard wall of the guide track that intersected the inboard upper guide track bolt hole. The fractured wall of each guide track had arc-shaped deformation features and inward and upward deformation, consistent with contact with the respective upper guide roller. The fracture features were consistent with overstress fracture, and there was no evidence of preexisting cracks or damage.

The outboard upper guide track bolt holes in both upper guide fittings were intact and showed no evidence of contact damage. Faint circular marks consistent with prior contact with washers associated with the upper guide track bolt were visible on the forward upper guide fitting during preliminary examinations.[37] The inboard upper guide track bolt holes had areas of intact enamel with no evidence of contact damage around the inboard sides. Areas with missing enamel had tension cracks corresponding to the outside of the bend from the curved roller contact deformation (see figure 12).

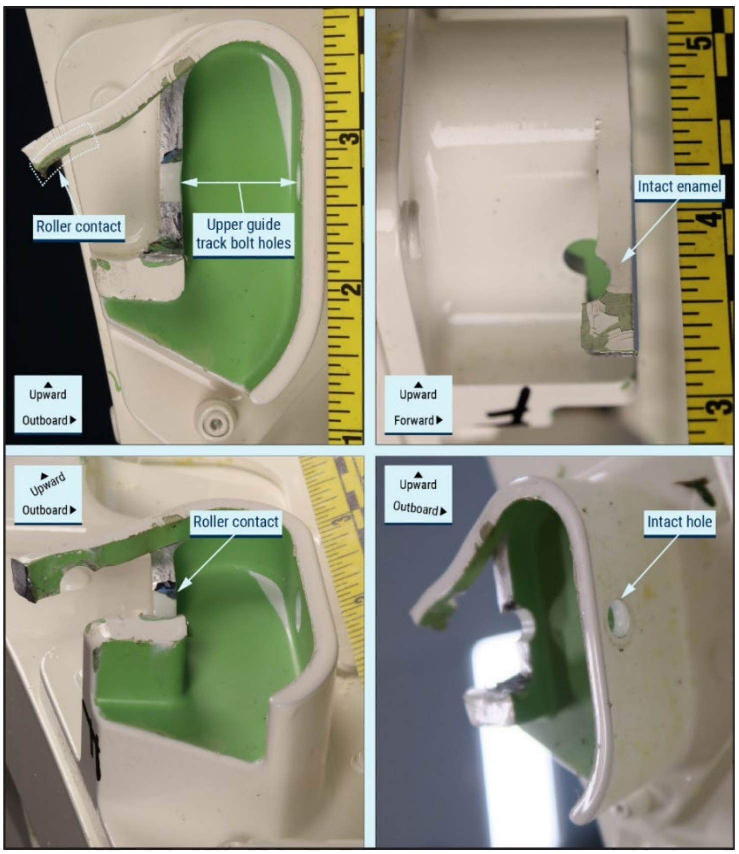


Figure 12. Multiple views of the forward upper guide fitting on the left MED plug.

[37] These areas were subsequently cleaned to facilitate examinations using a stereo optical microscope and a scanning electron microscope, and faint dark deposits remained visible.

The aft lower hinge guide fitting attachment flange was fractured at the two upper attach hole locations, and the bolts remained installed in the left MED plug. The two lower attach bolts were fractured. A similar damage pattern was noted on the left MED plug at the forward lower hinge guide fitting attachment location. All features were consistent with ductile overstress fracture. The vertical movement arrestor bolt holes in the aft lower hinge guide fitting were intact and undamaged (see figure 13).

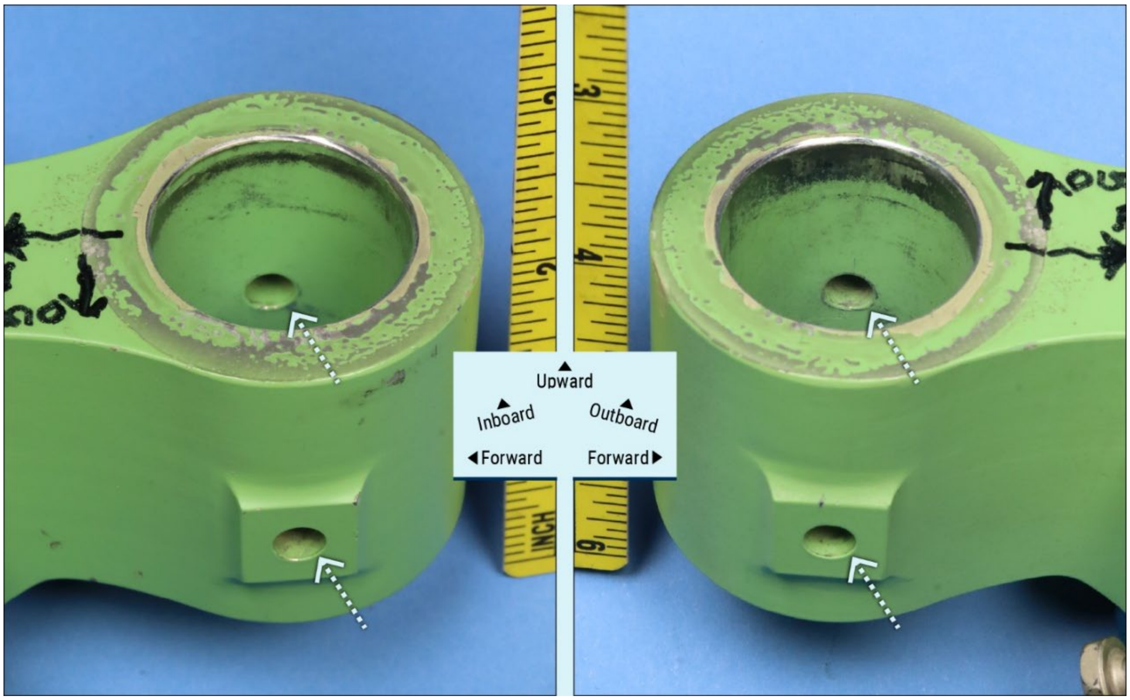


Figure 13. Photographs showing two views of the vertical movement arrestor bolt holes.

Note: Photographs show unlabeled arrows pointing at the inboard and outboard sides of the aft lower hinge guide fitting. (Marker labels and arrows added during the examination.)

The aft lower hinge fitting shaft was bent inboard about 3.7° with corresponding contact damage noted to the left MED plug lower beam. The outboard side of the vertical movement arrestor bolt hole was slightly elongated and exhibited small tensile cracks at the apex of the bend consistent with plastic deformation of the hinge fitting shaft; the hole bore was otherwise undamaged. The forward lower hinge fitting shaft was bent inboard about 0.4° with corresponding contact damage noted to the left MED plug lower beam. The vertical movement arrestor bolt hole bore was intact and undamaged.

1.10.1.2 Right Mid Exit Door Plug Examination, Opening, and Closing

The NTSB structures investigative group examined the accident airplane's right MED plug, which was undamaged and showed no evidence (or record) of having been opened since factory installation.[38] The right MED plug's upper guide track bolts and vertical movement arrestor bolts were in place, and the stop pins were aligned with the stop pads at all 12 locations. Petroleum jelly residue was identified on the upper seal area (identical to that identified on left MED plug).

The right MED plug served as an exemplar for the group to examine the opening and closing characteristics of a plug. During the examination, the two upper guide track bolts and two vertical movement arrestor bolts were removed, and the group observed that the right MED plug remained in place. To measure the amount of force needed to open the MED plug, the group attached a strap (to facilitate lifting the plug) and force gauge. An upward force of 120 lbs was applied (to the limits of the gauge) with no vertical movement of the plug. Additional force by two people, estimated to exceed 150 lbs, was applied, and the plug moved vertically upward, disengaging from the stops. After manipulating the plug several times, the force required to move the plug upward from its closed position continued to exceed the limits of the force gauge.

The investigation also measured the size of the exterior gap between the lower edge of the unsecured right MED plug (that is, with the bolts removed) and the fuselage opening at three vertical plug positions in the range of stop pin to stop pad contact: fully down (no upward movement), middle (some upward movement), and upper (consistent with the point of stop pin to stop pad instability). In the fully down,

[38] The group performed the examination concurrent with Alaska Airlines' inspection of the right MED plug in accordance with the FAA's January 6, 2024, emergency airworthiness directive (AD) (see section 1.12.1.1 for more information).

middle, and upper positions, the exterior lower gap was 0.079 inch, 0.315 inch, and 0.630 inch, respectively (see figure 14).

Figure 14. Exterior view of exemplar, unsecured right MED plug (from the accident airplane).

Note: The figure shows the visual appearance of lower gap at three plug positions in the range of stop pin-to-stop pad contact. The three positions shown are fully down, middle, and upper (at point of stop pin to stop pad instability).

1.10.1.3 Dynamic Loads Analysis

The airplane had accrued 154 flight cycles at the time of the accident, and QAR data were available for the last 9 flights. The Boeing Dynamic Loads group supported the investigative inquiry into how the accident airplane's left MED plug could remain on the airplane for the previous flight cycles but move upward (as described in the previous section) to the point of stop pin to stop pad instability such that it could separate from the airplane during the accident flight. The group applied a modeling technique to the airplane vertical acceleration data from the QAR to estimate the inertial loads on the left MED plug during ground operations, climb, and descent.[39]

The group focused on instances where the estimated inertial loads on the MED plug were less than 1.0 g and reduced the effective weight of the plug. (The nominal weight of the MED plug at 1.0 g was 63 lbs.) The results determined the smallest estimated load of 0.40–0.45 g occurred once and estimated loads of 0.45–0.50 g

[39] Ground operations were defined as taxi, takeoff, and landing operations with no cabin pressurization loads, climb was defined as the time during ascent when the internal cabin pressure was increasing until stabilized at the maximum for the given flight, and descent was defined as the time during descent when the internal cabin pressure was decreasing from the maximum for the given flight to zero.

occurred twice in the 106,008 values counted for the 9 flights for which data were available.[40] The 0.40–0.45 g level represented an effective plug weight of 25 lbs.

1.10.1.4 Design Capability with Various Missing Bolts

As described previously, per airplane design, an MED plug was designed to be secured with two vertical movement arrestor bolts and two upper guide track bolts to prevent upward movement. Boeing conducted an engineering review to determine MED plug design capability in various missing bolt configurations.

The engineering review determined that an installation with only one vertical movement arrestor bolt (with both upper guide track bolts and the other vertical movement arrestor bolt missing) was capable of preventing upward movement of the MED plug. Also, an installation with only the two upper guide track bolts (with both vertical movement arrestor bolts missing) could sufficiently limit upward movement of the MED plug to prevent disengagement of the stop pins from the stop pads.

1.10.2 Cabin Pressurization System

As discussed in section 1.5.3, the accident airplane's cabin pressurization system was equipped with two CPCs, with one serving as the CPC-in-command and the other serving as backup (and alternating each flight leg).

Postaccident testing of both CPCs (performed in accordance with the applicable aircraft maintenance manual procedures) identified no faults, and production level system status tests (performed based on Boeing engineering guidance and testing criteria) identified no anomalies or unexpected values. Both CPCs were tested by the manufacturer and passed the manufacturer's acceptance test procedure.

Each CPC was equipped with nonvolatile memory that provided historic information about CPC performance. The following sections describe the data for the accident flight and previous flights, including those for which Alaska Airlines' maintenance records documented that the AUTO FAIL light had illuminated. (The AUTO FAIL light will illuminate to alert the flight crew of certain anomalous conditions involving the cabin pressure control system, such as the failure of a CPC.)

[40] The group estimated an error of about +/- 0.15 g.

1.10.2.1 Data for Accident Flight

A review of the QAR data for the accident flight showed that, during the climb after takeoff, the cabin pressurization system was in automatic mode, and the cabin pressure tracked according to the predicted pressurization schedule.[41]

The data showed that, at the time the cabin pressure rapidly decreased (at 1712:33), and the 10,000 ft Cabin Altitude Warning alerted, the CPC-in-command commanded the outflow valve to move to the closed position to attempt to maintain cabin pressure. Shortly thereafter, the outflow valve pressure switch activated, which overrode commands from the CPC and forced the outflow valve to remain in the fully closed position. Once the airplane altitude decreased below about 14,760 ft, the CPC again took control of the outflow valve position and attempted to maintain cabin pressure in accordance with applicable cabin altitude descent rate limitations until the time that the system was put into manual mode.

The data showed that, about 1715:07, both CPCs went into standby mode (indicating that the flight crew placed the cabin pressure control switch into manual mode), and shortly thereafter, the crew manually commanded the outflow valve to move to fully closed, where it stayed for the remainder of the flight.[42]

Data retrieved from the nonvolatile memory in each CPC indicated no faults or status messages were recorded for the accident flight until the "CABIN 10000 FT MESSAGE" occurred (as would be expected for a rapid depressurization event occurring above 10,000 ft).

1.10.2.2 Previous AUTO FAIL Light Illumination Events

As stated in section 1.5.1, Alaska Airlines' maintenance records for the accident airplane documented that the AUTO FAIL light had illuminated during previous flights, with the most recent two events occurring on each of the 2 days before the accident flight.

Data retrieved from the nonvolatile memory of both CPCs recovered from the accident airplane showed that, since airplane delivery, the AUTO FAIL light illuminated during four different flights.[43] One event was recorded for one CPC, and

[41] QAR data were referenced because the QAR recorded more parameters related to the cabin pressurization system than the FDR recorded.

[42] The QRH procedure for a Cabin Altitude Warning directs the flight crew to select manual pressurization and drive the outflow valve fully closed before beginning an emergency descent.

[43] The data showed the events occurred on November 10, 2023; December 7, 2023; January 3, 2024; and January 4, 2024.

three were recorded for the other. The CPC fault signature was identical for all four events.

According to the CPC manufacturer, the fault signatures recorded in the CPCs for the historical AUTO FAIL light events were consistent with an intermittent failure of the CPC's universal asynchronous receiver-transmitter (UART) microchip.[44] Per system design, each of the identified faults would result in the affected CPC automatically transferring cabin pressure control to the alternate CPC.

QAR data were available for the flights involving the two most recent AUTO FAIL light events. These data showed that, when the faults occurred, the alternate CPC automatically took command, and there was no disruption or obvious effect to cabin pressure control. The data showed that the cabin pressure remained at the expected values based on the designed pressurization schedule before, during, and after these AUTO FAIL events.

CPC data for all four events showed that, following each occurrence, the pressurization system was not put into manual mode. (Per flight crew procedures, if the automatic system were not operating normally, the crew would respond by selecting manual mode.)

1.10.3 Cabin Supplemental Oxygen Equipment

1.10.3.1 Passenger Service Units

Postaccident examination of the supplemental oxygen service units revealed that all oxygen masks deployed at each flight attendant station, lavatory, and passenger service unit during the depressurization event. For the three flight attendant stations that were occupied at the time of the depressurization event, the oxygen masks had been activated. None of the lavatory oxygen cylinders had been activated. (The lavatories were unoccupied during the accident flight.)

For each passenger service unit, the retaining pin was found disengaged from the chemical oxygen generator, and the temperature-sensitive indicator strip had changed color (due to heat exposure), indicating that the generator had produced oxygen. Sixty of the 62 chemical oxygen generators installed on the accident airplane (all except the generators installed at seat units 1AB and 25DEF) were found displaced aft from their installed positions. All remained attached to their respective oxygen tubes.

[44] The manufacturer's review of repaired CPCs between January 2021 and December 2023 found that 10 of 585 repaired units showed the same fault code sequence, and each of the 10 units had UART microchips from the same lot as the microchips in the accident airplane's CPCs.

The displaced generators were each equipped with flat pads under their two retention straps; some generators had moved aft as much as 0.75 inch and were completely free from the retention strap at their forward end. The two generators that did not move from their installed positions were equipped with a different style of pad (which had a groove in which the retention strap fit), and their retention straps were in place over the pad.

In 2023, Boeing received two reports (one in April and one in December) from an operator that identified (during a routine inspection) multiple displaced oxygen generators on two airplanes that had accumulated about 25 flight hours each. There was no documented malfunction of the oxygen system associated with these events. Boeing evaluated the events with the FAA and identified an issue with the pressure-sensitive adhesive on the flat pads on passenger service units provided by a supplier from August 2019 through December 2023. The units delivered during this period potentially affected as many as 541 Boeing 737 MAX airplanes and 138 Boeing 737 NG airplanes.

In December 2023, Boeing discontinued the installation of the flat pads, using only the grooved pads on new production airplanes. Boeing drafted service bulletins to inspect in-service airplanes and retrofit them, as needed, with the appropriate pads. At the time of the accident, Boeing and the FAA’s actions related to the issue were ongoing but have since been completed (see section 1.12.2.6).

1.10.3.2 Portable Oxygen Bottles

As stated in section 1.9, flight attendants D and B used two of four available portable oxygen bottles (one each from the forward cabin and seat unit 32ABC locations). Postaccident examination of the cabin found one portable oxygen bottle in each stowage location still secured by its respective securing bracket with the masks (one attached and one spare) and tubing still in their packaging, and the gauge showing a reading of 1750 psi.

One portable oxygen bottle was found leaning upright in the forward cabin stowage compartment unsecured by the bracket with one mask out of its packaging and unfolded with the tubing uncoiled. The spare mask remained in its packaging, and the gauge read 0 psi, indicating that the oxygen bottle was empty.

Another portable oxygen bottle was found lying on seat 34D; one mask was found out of its packaging and unfolded with the tubing uncoiled. The spare mask remained in its packaging, and the gauge read 1450 psi.

The opened masks on each bottle consisted of a plastic bag with two exhalation (vent) holes, a flexible metal nose strip, and an elastic strap (see figure 15).

Figure 15. Side-by-side photographs of the mask and shoulder strap of a portable oxygen bottle on the accident airplane being worn (left) and a closeup of the packaging for a spare mask and tubing (right). (Source for both photographs: Boeing)

Each portable oxygen bottle was manufactured by AVOX under an FAA parts manufacturer approval.

1.10.4 Interphone Equipment and Flight Crew Oxygen Mask Microphones

As stated in section 1.1, some flight attendants used interphones to communicate with each other and the flight deck but reported difficulty hearing responses. Postaccident testing of all three interphone handsets and the flight crew oxygen mask microphones revealed normal audio volume and clarity. Also, communications over the public address system were audible when test announcements were made from each interphone, flight crew headset, and flight crew oxygen mask. The postaccident testing, which was performed with the airplane on the ground, could not replicate the environmental conditions present during the accident flight, such as the noise and rushing air in the cabin and the flight deck.

1.11 Organizational and Management Information

1.11.1 Airplane Operator

Alaska Airlines, a Part 121 operator, began operating under that name in 1944, after the mergers of smaller companies dating back to 1932. Alaska Airlines acquired Virgin America in 2016 and began operating as a single airline under the Alaska Airlines brand in 2018.

Alaska Airlines had a fleet of 231 Boeing 737 airplanes, including Boeing 737 NG (Boeing 737-700, -700F, -800, -800F, -900, and -900ER) and Boeing 737 MAX (Boeing 737-8 and -9) models. At the time of the accident, it had 65 Boeing 737-9 airplanes.

1.11.1.1 Flight Crew Procedures and Training

The "CABIN ALTITUDE WARNING or Rapid Depressurization" emergency procedure for the Boeing 737-9 (which the flight crew referenced during the accident flight) included items related to the use of emergency oxygen masks. The first two items on the list stated that the pilots should don their emergency oxygen masks and establish communications. It also stated that, when the cabin altitude was below 10,000 ft, the oxygen masks may be removed.

The Alaska Airlines 737 Systems Handbook described the flight crew oxygen masks and communications procedures for both the Boeing 737 NG and Boeing 737 MAX airplanes. The "Airplane General Differences" section of the handbook stated the following about the oxygen mask system for the Boeing 737 MAX airplanes (emphasis in original):

> There is no MASK-BOOM switch on the Audio Control Panel. With the Flight Crew Oxygen Mask removed from the stowage box (right stowage box door open), the mask microphone is automatically selected and the boom microphone is deselected. When the right stowage box door is closed, the TEST/RESET switch is actuated, and the OXY ON flag is no longer displayed, the mask microphone will be deselected and the [headset] boom microphone will be selected.
>
> **Stowage Box**
>
> The **TEST/RESET Switch** (spring-loaded) when positioned to TEST/RESET and released with the mask right Stowage Door closed and the:

> - OXY ON flag not displayed, will activate the oxygen flow and Mask Microphone momentarily to operationally test the regulator
> - OXY ON flag displayed, shuts off oxygen flow to the mask and disables the Mask Microphone and enables the Boom Microphone.

The Alaska Airlines initial familiarization computer-based training module contained a slide that stated the following about Boeing 737-9 differences (emphasis in original):

> If the flight **Crew Oxygen Mask is removed from the stowage box or the right stowage door is open**, <u>the mask mic is automatically selected</u> and boom mic is deselected.
> TO RESET:
> • Right stowage box door must be closed
> • TEST/RESET switch (on O2 stowage) actuated
> • OXY ON flag is no longer displayed
> Then the mask mic will be deselected and boom mic selected.

For hands-on emergency equipment training, Alaska Airlines used a mockup trainer that contained oxygen masks (and their respective stowage boxes) for both the Boeing 737 MAX and Boeing 737 NG airplanes. The mockup trainer was not equipped with headset jacks or audio control panels. From June 1 to December 31, 2020, due to the COVID-19 pandemic, Alaska Airlines exempted donning oxygen masks during training.

The investigative group observed Alaska Airlines' simulator scenarios that demonstrated (among other procedures), the flight crew procedures for rapid depressurization, including oxygen mask use and crew communications, for both the Boeing 737 MAX and Boeing 737 NG airplanes. During the observations, investigators discovered that, before the accident, the three simulator instructors who assisted with the simulator scenarios were not aware and not teaching that, after the oxygen mask is removed and the stowage box right door closed, the TEST/RESET button must be actuated to deselect the oxygen mask microphone and reestablish communications back to the headset boom microphone in the Boeing 737 MAX airplanes. (Alaska Airlines subsequently updated its pilot training; see section 1.12.4.3.)

1.11.1.2 Cabin Crew Procedures and Training

The Alaska Airlines flight attendant manual (FAM) current at the time of the accident contained information and procedures for flight attendants related to rapid depressurization. Per the manual, in the event of a rapid depressurization, flight attendants were expected to immediately don the nearest oxygen mask and secure themselves by any means available. It stated that, if possible, the flight attendants should advise the flight crew that masks had dropped and follow their instructions.

The FAM also stated that the flight attendants should expect that the pilots would perform an emergency descent, the automatic depressurization announcement would play, and the cabin lights would default to the brightest setting. It stated that flight attendants should expect communication from the pilots about when oxygen was no longer necessary, when it was safe to move around the cabin, and whether they needed to brace for an imminent emergency landing.

The FAM stated that, "if the [airplane] has leveled off and there has not been any communication from the pilots, attempt to contact the pilots before removing oxygen or moving about the cabin." It stated that, if oxygen was still needed, flight attendants should "move from mask to mask" through the cabin (using extra masks at each passenger seat unit) to reach a location to obtain and don a portable oxygen bottle.[45] They were expected to ensure that passengers are using oxygen masks correctly and that oxygen is flowing. The FAM stated that, once oxygen was no longer needed, the flight attendants could move through the cabin and perform such duties as checking on passengers and other flight attendants, checking lavatories, providing first aid, checking the cabin for structural damage, and reporting to the flight crew.

Alaska Airlines' initial training for newly hired flight attendants included a 90-minute instructor-led session on airplane cabin depressurization that provided a demonstration of both slow and rapid depressurization using inflated balloons, information and a video about the physical effects of a rapid depressurization, including hypoxia, and information about the time of useful consciousness (also provided in the FAM). The training covered the importance of immediately obtaining oxygen and securing themselves, the commands to issue in case the automatic announcement didn't play, and the need to assess the situation and communicate with the other flight attendants and the pilots. The training also discussed an accident case study and included an in-person demonstration (by the instructor) on donning and using a portable oxygen bottle.

Alaska Airlines' recurrent training for flight attendants included a computer-based training module on rapid depressurization that contained slides that discussed the typical causes and characteristics of such an event and the procedures prescribed in the FAM.

[45] The FAM also described the use of portable oxygen bottles, including how to turn on the valve to start the oxygen flow, check the oxygen flow, and don the mask.

1.11.2 Airplane Manufacturer

The Boeing Company develops, manufactures, and provides support for commercial airplanes, defense products and space systems. As stated in section 1.1, the Boeing 737-9 airplane is manufactured by the Boeing Commercial Airplanes business unit (referred to in this report as "Boeing"). Final assembly of Boeing 737 airplanes is accomplished in Boeing's Renton, Washington, facility.

Spirit AeroSystems, one of the world's largest manufacturers of aerostructures for commercial airplanes, business and regional jets, and defense aircraft platforms, is a major supplier of Boeing 737 and 787 fuselages to The Boeing Company. Spirit AeroSystems is headquartered in Wichita, Kansas, with facilities in the United States, United Kingdom, France, Malaysia, and Morocco (Spirit n.d.).

The Spirit AeroSystems facility in Malaysia manufactured the accident airplane's left MED plug on March 24, 2023, in accordance with applicable engineering drawings.[46] The Spirit AeroSystems facility in Wichita received the left MED plug on May 10, 2023, and installed it on the fuselage on July 18, 2023.[47] The same facility also installed the respective edge frame assembly (into which the left MED plug was installed) on the fuselage.

Records showed that Spirit AeroSystems personnel in Wichita completed the final closure of the left MED plug on July 28, 2023, which, per the specified production order, included installing the two upper guide track bolts and two vertical movement arrestor bolts per the "close and verify" step. The fuselage was shipped to Boeing on August 20, 2023, and arrived at Boeing's 737 production facility in Renton on August 31, 2023.

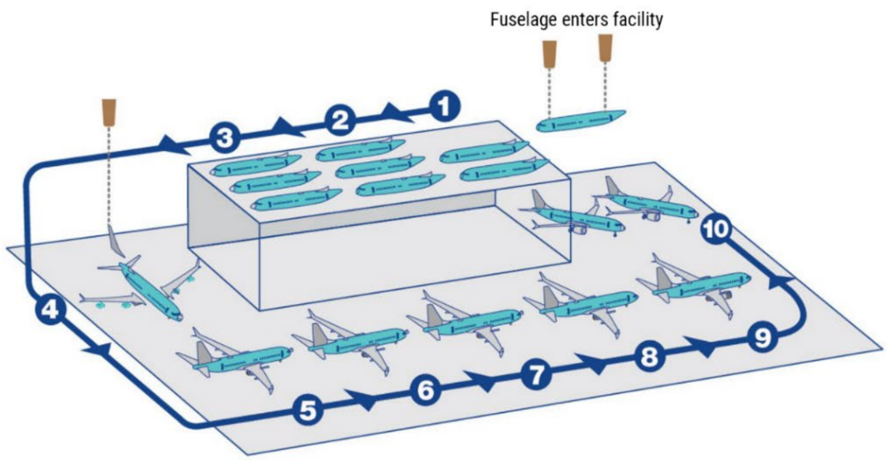
1.11.2.1 Assembly Process at Boeing Commercial Airplanes' Renton Facility

The final assembly process for Boeing's 737 production was typically divided into 10 factory positions referred to as "flow days," with a specific work scope performed at each flow day position. Boeing installation plans (IP) provided the baseline work instructions that manufacturing personnel followed to build the airplanes to engineering drawings and product standards. The IPs consisted of

[46] Spirit AeroSystems Malaysia's records for the left MED plug showed manufacturing discrepancies that were subsequently corrected per process. The noted discrepancies were torque wrench serial numbers not being recorded and sealant and paint information not being provided in the applicable production orders.

[47] The Spirit AeroSystems Wichita facility documented a discrepancy for the left MED plug related to its seal flushness being out of tolerance by 0.01 inches. A Spirit AeroSystems engineering review determined that the condition did not adversely affect the fit, form, or function of the installation, and no manufacturing rework was required.

defined plans to be performed sequentially (known as order precedence) at specified flow days as the airplane moved through the factory in the manufacturing process (see figure 16). IPs also provided a means for Boeing personnel to document the completion of each step and, if required, for Boeing quality assurance personnel to sign off the completion of each step in the IP and to apply the final signoff of the IP after all steps were completed.



Flow day	Interior installation	Exterior installation	Testing
1 2 3	•insulation blankets •hydraulic systems •electrical wiring	•dorsal fin •protective radome •MED rig verification	
4		•wings •horizontal stabilizers •vertical stabilizer •landing gear	
5	•rear galleys •lavatories	•cable riggings connected to flight controls	•fuel tank pressure
6	•sidewalls, •overhead stowage bins •forward galleys		•mechanical •electronic
7			•cabin pressure •landing gear •flight controls
8	•carpets •seats		•flight controls •hydraulics
9		•engines •MED fit and fair	
10	Final wrap up and exterior airplane protection.		

Figure 16. Flow days for Boeing 737 production line. (Source: Adapted from a Boeing diagram.)

Boeing manufacturing records showed that, on September 1, 2023, as part of IP "OK to Install Blankets," Boeing personnel at the Renton facility performed a routine inspection of the accident airplane's fuselage IP "OK to Install Blankets," which was to be performed at flow days 1 through 3, specified several steps to ensure there were no workmanship issues (such as bent brackets or structures, riding conditions, open holes, fastener conditions, tool marks, and other discrepancies) on the fuselage structure before the insulation blankets could be installed on the fuselage interior.

While performing IP "OK to Install Blankets" for the accident airplane's fuselage, Boeing personnel identified workmanship discrepancies with five rivets in the edge frame forward of the left MED plug, and, per Boeing process, initiated a nonconformance record (NCR), which documented the discrepancies, and a nonconformance order (NCO) "Damaged Rivets," which provided the work instructions for performing the rework required by the NCR.[48]

Per Boeing process, the IPs, NCRs and NCOs were recorded and tracked for the accident airplane's fuselage in Boeing's web-based manufacturing records system, Common Manufacturing Execution System (CMES). Boeing employees used CMES to access information required to support the production process and to record the completion and quality assurance signoff of all work instructions, including inspections and the resolution of nonconformances.

Per Boeing process, NCRs and NCOs (such as the NCR and NCO generated for the rivet discrepancies) are linked as exceptions to the source IP (for example, IP "OK to Install Blankets"). IPs with linked exceptions remain open until the exceptions are cleared in CMES.

The records for the accident airplane documented that IP "OK to Install Blankets" was started and then "short stamped" on September 1, 2023. According to Boeing, a short stamp is the application of a stamp that indicates a portion of the operation or process has been completed. Boeing personnel applied the short stamp to sign off all but the final step of IP "OK to Install Blankets" due to the open exceptions.

According to Boeing, the final step in an IP was a hard-coded final operation on CMES orders that precludes the application of final authority media in CMES until all previous steps in the IP were stamped as completed and all exceptions were documented as having been cleared. Per Boeing process, any IP not completed at its

[48] A rework NCR recorded conditions on material, parts, assemblies, installations, data sheets, equipment, or test operations that were unsatisfactory or did not conform with engineering drawings or specification requirements but that could be corrected without an engineering disposition that would change the type design data. An NCO was a work instruction document that manufacturing and quality personnel followed to perform rework or repair required by an NCR.

specified flow day position was considered "traveled work." Work associated with any NCR and NCO linked to an IP and not accomplished on the flow day the NCR and NCO was generated was also considered traveled work. (See section 1.11.2.1.3.)

Boeing IP "Installation of Insulation Blankets," scheduled for flow days 1 through 3, contained steps to install insulation blankets on the fuselage interior—including the area around the left MED plug. Boeing's records showed that this IP was initiated and completed on the accident airplane's fuselage on September 1, 2023, with no exceptions. Boeing's postaccident review of this IP determined that the initiation of IP "Installation of Insulation Blankets" before IP "OK to Install Blankets" was completed was not consistent with the IPs' order precedence (that is, the sequence in which the work was to be performed).

Boeing used a cross-functional communication tool, the Shipside Action Tracker (SAT), which provided a means for manufacturing and function support personnel to document requests for assistance and the responses to each request. Communication entries for a particular SAT were not aircraft production records but provided the means to track the communications about a specific issue, such as the NCR and NCO "Damaged Rivets" for the discrepant rivets on the accident airplane's fuselage, and elevate awareness (for example, to management, if needed) that drove actions to resolve build issues.[49] Once a SAT was generated, it tracked a chronological listing of the communications; the date and time associated with a SAT entry indicated when the entry was made.

1.11.2.1.1 Rework Requiring Opening Left Mid Exit Door Plug

Records showed that Boeing personnel initiated a SAT on September 1, 2023, to track and support the request from Boeing personnel to Spirit AeroSystems representatives to address the discrepant rivet issue documented by the NCR and NCO linked to IP "OK to Install Blankets."[50]

Per Boeing's manufacturing process, Spirit AeroSystems personnel were not authorized to remove completed installations on a fuselage to access a work area;

[49] For the Boeing 737 production line, Boeing retained SAT communications records and production records (such as IPs, NCRs, and NCOs) for the life of the product plus 10 years.

[50] Spirit AeroSystems employed several personnel who were on site at Boeing's Renton facility to address any manufacturing discrepancies related to work performed by Spirit or a Spirit supplier. The discrepant rivets had been installed by Quik Tek, a Spirit supplier. Spirit employed a senior manager for manufacturing who oversaw Spirit's on-site personnel. At the time the accident airplane was assembled, Spirit personnel at Boeing's Renton facility included 4 managers, 20 mechanics, and 2 quality assurance personnel, all of whom were independent contractors hired locally.

only Boeing personnel were allowed to perform such work.[51] Also, Boeing quality assurance personnel were responsible for performing the final inspection signoff. Spirit AeroSystems' representatives agreed that Spirit would perform the rivet rework once Boeing personnel provided access to the work area.

To allow access for the removal and replacement of the discrepant rivets, Boeing personnel needed to open the left MED plug, which inherently involved removing the four bolts (and associated castle nuts, cotter pins, and washers) that secured the plug. Per the guidance specified in Boeing's business process instruction (BPI) "Perform Part or Assembly Removal," opening the MED plug met the criteria for activities that required the initiation of a removal record.[52] Per the BPI, the purpose of a removal record, in part, was to:

- Ensure that the product was restored according to all released engineering requirements.
- Make certain that there was a record in CMES that a previously accepted installation was disturbed.
- Confirm configuration accountability through completed records of all activity occurring on aircraft parts and installations.

A removal record was typically generated by the person who performs the task, and its status was tracked in CMES. Like NCRs and NCOs, a removal record would be linked to source IP that identified the needed rework. (For example, in the case of the accident airplane's fuselage, IP "OK to Install Blankets," which identified the discrepant rivets.)

Removal records ensured that any previously applied quality assurance acceptances associated with the installation were removed. The removal record listed the steps that needed to be performed to restore the disturbed installation back to an accepted status, per the applicable engineering requirements, and it specified any signoffs from manufacturing personnel, quality assurance inspectors, or both associated with each step, as well as the final quality assurance signoff.

[51] Spirit AeroSystems managers in Renton coordinated with Boeing any requests for access, and Boeing personnel removed any parts required to access the work area. Spirit mechanics performed rework in accordance with Boeing processes and work instruction documents.

[52] The BPI provided guidance on the removal documentation requirements associated with manufacturing tasks involving the disturbance of completed installation, such as removing, partially removing, loosening, or disassembling a previously installed and accepted component, part, assembly, or standard. The BPI also listed exceptions and provided a decision tree for determining which activities were not subject to the removal record requirements (see section 1.11.2.3.3 for more information).

No removal record for opening the left MED plug was identified in CMES, and Boeing's search of all other available record sources identified no evidence that one had been created.

1.11.2.1.2 Timeline for Opening and Closure of Left Mid Exit Door Plug

Numerous Boeing and Spirit AeroSystems personnel whose job duties on the Boeing 737 production line provided some opportunity for potential awareness of activities, processes, or both related to the left MED plug provided a postaccident statement. Seventeen Boeing 737 production line personnel who provided statements also participated in follow-up interviews with the NTSB.[53] None of the personnel who provided information indicated that they had any knowledge of who opened the left MED plug, why no removal record existed, or who performed the final closure.

The NTSB reviewed a variety of data sources to determine the timeline of events from the initial September 1, 2023, request for the rivet rework to approximate times that the left MED plug was opened and closed. These data included CMES records (including NCRs and NCOs), SAT communications entries, and additional information provided by Boeing and Spirit AeroSystems, including employee emails, text messages, photographs, timecards, fuselage work area entry and exit records (known as barge logs), statements, and interviews.[54]

As stated in the previous section, Boeing personnel initiated a SAT on September 1, 2023, to track communications about the work related to the NCR and the NCO "Damaged Rivets" (linked to IP "OK to Install Blankets") that identified the need for Spirit AeroSystems personnel to rework the five discrepant rivets in the forward edge of the fuselage frame for the left MED plug. (Most of the subsequent

[53] Boeing 737 production line personnel who provided statements to the investigation included 24 door team personnel, the door manager (who was on long-term medical leave during the investigation but later provided a statement), 2 quality assurance inspectors, 2 senior managers, a blanket installation manager, and others. Spirit AeroSystems personnel (and independent contractors who performed work on behalf of Spirit) who provided statements were three managers, three mechanics, and one quality assurance inspector. The Boeing 737 production line personnel who also participated in interviews were five door team members, a quality assurance inspector, three interior seat installers, a functional test team lead, a shipside operation specialist, an interiors manager, a second-level general supervisor, a front-line manager, a first-line supervisor, a first-level manager, and the former vice president and general manager of the Boeing 737 production line. Spirit personnel interviewed included a manager, a mechanic, and a quality assurance inspector.

[54] No Boeing security video recordings of the accident airplane's build process were available. Boeing maintained such recordings for 30 days, and the accident occurred after this period.

entries for this SAT were made by Boeing line side control center personnel. Spirit personnel did not have access to the SAT.[55])

The NCO showed that, on September 6, 2023, a Spirit AeroSystems contract mechanic and contract quality assurance inspector documented that the rivets were removed and replaced. The NCR showed that, on that same date, Boeing quality assurance personnel documented that the rivets were not removed and replaced but "just painted over." (The rivet work that was performed did not require opening the left MED plug because it did not require the same access that would be needed to remove and replace the rivets.) On the date of the SAT entry, the accident airplane was still at flow days 1 through 3.

According to Spirit AeroSystems, the contract mechanic who documented that the rivets were removed and replaced "incorrectly stamped what work was performed…. He stated that he had confused [the accident] airplane with another airplane he was working on that day."[56]

The NCO reflected that, on September 8, 2023, Spirit applied its supplier acceptance to the rivet work, stating that the "noted rivet bucktail damage is acceptable." The NCO reflected that, on September 11, 2023, Boeing personnel again removed Spirit's supplier acceptance, indicating that "damaged rivets are not acceptable and need to be replaced."

A SAT entry on September 14, 2023, at 1249 elevated the issue from Tier 1 to Tier 2 to enhance Boeing management visibility, and a SAT entry the next day stated that Spirit management indicated that access and removal are needed. (Tier 1 included the first-line leaders, Tier 2 included the second-level managers, and Tier 3 included the director.) On the date of this SAT entry, the accident airplane was at flow day 9.

A SAT entry on September 17, 2023, at 0841 documented that there was no access to the rivet work area. A SAT entry the same day at 1554 indicated that the issue was elevated from Tier 2 to Tier 3 for additional Boeing management visibility, and it included a note that, "LSCC [line side control center personnel] will help coordinate with first shift to gain access to the damaged rivets, which include opening/removing the mid exit door." A subsequent 1815 entry that same day

[55] According to a Boeing shipside operation specialist (which is a line side control center position), his role involved assisting manufacturing personnel who have build constraints to get them the resources they need to complete their assigned task. He said that part of that role involved using the SAT to communicate their needs, coordinate obtaining information and personnel assistance, and documenting status updates related to the task.

[56] Spirit AeroSystems' senior manager for manufacturing, general support, provided this information during testimony at the NTSB's public hearing for this accident on August 6, 2024.

indicated that a Boeing senior manager worked with the door manager to determine the actions needed for access. The entry stated, “If removal needed, a removal needs to [be] written first.” On the date of this SAT entry, the accident airplane was at flow day 10.

When interviewed, the Boeing general supervisor, second level, who was referenced in this SAT entry (and was, at the time, located in a different part of the facility than where the accident airplane’s fuselage was located) stated that the SAT entry information referred to her need to know how the fuselage was equipped so that the appropriate personnel could be assigned to perform the task (see section 1.11.2.1.2 for more information). She said that once she learned that the fuselage was equipped with an MED plug, she determined that no door team member who could open the MED plug was available, that the work was not part of the weekend plan, and that the work would have to wait until door team personnel were there during the week. She said that she escalated the issue from Tier 2 to Tier 3 to let those managers know that there was a build issue. She said that needing to open an MED plug was a “one off” situation that she hadn’t seen before and that door team personnel typically open doors, not plugs.

A SAT entry on September 18, 2023, at 0700 documented that the issue was downgraded from Tier 3 to Tier 2 and that the Boeing door manager indicated that the “door is being opened by mechanic.” A SAT entry at 1100 that same day stated that, per a Spirit AeroSystems manager, “access is now available,” and that a Spirit mechanic would be assigned to perform the rivet rework.

The investigation determined the left MED plug was open at least as early as 1053 on September 18, 2023, and remained open until at least 1709 on September 19, 2023, to allow access for the rivet work. Figure 17 shows the timeline for the opening and subsequent closure of the left MED plug based on the investigation’s review of all available information.

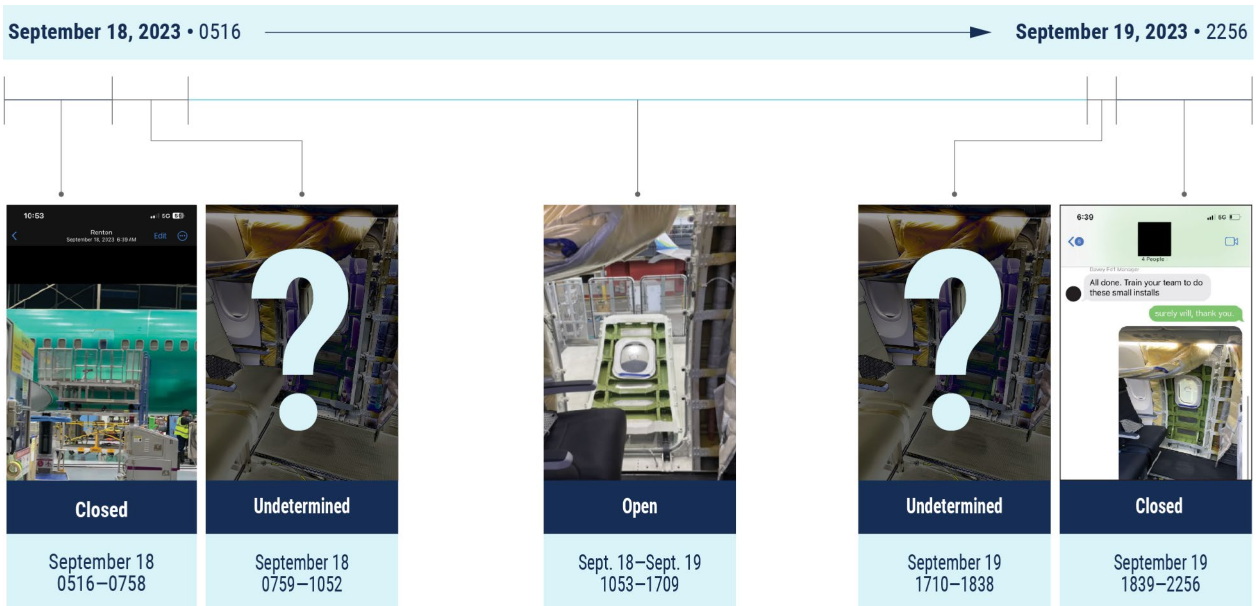


Figure 17. Timeline showing the periods for which evidence indicated the left MED plug was in a closed or open position and the periods for which its position was undetermined.

The timeline for the left MED plug's opening and closure enabled the investigation to determine which personnel with the skillset to perform those activities may (or may not) have been available to assist with the task. On the day the left MED plug was opened, the most experienced door team member who was typically tasked with opening an MED plug, should the need arise, was unavailable to assist because he was on leave that day and the next day. (Opening an MED plug was a nonroutine task performed only when needed to address a problem, which he said did not occur very often. See section 1.11.2.2.2 for more information.)

According to Boeing barge logs for the accident airplane's fuselage, the door manager, a door master lead, and three door team members had shielded in (that is, used their employee badges to log their access to the work area) at the fuselage the morning that the left MED plug was opened.[57] In response to investigative questions, the door manager provided a statement that indicated that he did not have an independent memory of asking that the left MED plug be opened, did not recall whether he saw the left MED plug opened at any time, and did not know why a

[57] During testimony at the NTSB's August 2024 investigative hearing for this accident, Boeing's senior vice president of quality stated that, per process, employees typically shielded in and shielded out when entering an area that was not their usual work area. She said they did not typically shield in and shield out when working in their normal daily work area. She stated that, at the end of a shift, if an employee had shielded into an area but didn't shield out, the manager would receive a notification.

removal record was not generated. (As stated previously, the door manager was on medical leave at the time the NTSB conducted investigative interviews.)

The door master lead who was on duty the day the left MED plug was opened said in an interview that the door manager asked him to go to the airplane and open a "mid door" (which, he said, would involve just using a handle to open) so that Spirit could rework the damaged rivets. He said that, when the manager subsequently clarified that it was "probably a plug," he informed the manager that (unlike a door with a handle) opening a plug would require special tools. He stated during the interview that he didn't have the tools (and wasn't sure what tools were needed) and that he had never opened an MED plug.

When asked, he stated that he did not know whether someone from his crew (referring to the door personnel on his team) opened the left MED plug but stated, "I can honestly tell you they didn't. I know my crew, I know how they operate." The three other door team members who had shielded in that morning participated in interviews and, as stated previously, indicated they had no knowledge of who opened the left MED plug.

During an interview, a Boeing functional test technician team lead (who was not a door team member) who worked second shift on September 18, 2023 (1330 to 2330) recalled being asked to move a stand away from the airplane that he believed (based on his review of production records) was the accident airplane.[58] He recalled that the airplane's left MED plug was lying open on the stand, so he went inside the airplane and used a strap to pull the plug up off the stand. He said he "just strapped it up there and let it hang," leaving a gap around it in the frame.[59] (As stated previously, evidence indicated that the left MED plug was still open at 1709 on September 19, 2023, which was after the functional test technician team lead performed his work to move the stand.)

The left MED plug's position was undetermined on September 19, 2023, between 1710 and 1838, while the accident airplane was at flow day 10. Text messages between Boeing personnel discussing interior restoration after the rivet rework was completed provided evidence that the left MED plug was closed during second shift operations that day, when no door team members were on duty. The

[58] Part of his team's responsibilities involved preparing airplanes to be moved from the factory outside to the preflight area, which included removing stands and tooling and protecting the airplane from contact and weather damage. The airplane continued to move along the production line while awaiting the rivet rework; for example, insulation, interior panels, and seats were installed in locations except the location near the left MED plug. The functional test team lead was asked to move the stand to enable adjustments to the airplane's struts, which was a subsequent step in the production process.

[59] He said that, typically, by the time an airplane reaches his team, the sidewalls and seats were installed, and he wouldn't be able to see the MED plug except from the outside.

texts included a photograph sent about 1839 that showed the plug in a closed position with no attachment hardware in the three locations visible (see figure 18).

Figure 18. Photograph showing the left MED plug in the closed position with arrows indicating the locations of missing attachment hardware. Source: Boeing, cropped by NTSB.

Note: Locations circled show where both vertical movement arrestor bolts and the forward upper guide track bolt are not installed; the aft upper guide track fitting is obscured from view.

During the NTSB's investigative hearing for this accident, Boeing's senior vice president of quality stated that, per Boeing's production process, only a door team member would be allowed to close an MED plug, which, for the accident airplane, could have been accomplished by either having a door team member stay late to perform the work during the second shift or waiting until the next day when the door team members arrived for their regular shift.

She initially indicated her belief that "move crew" personnel (whose duties involved ensuring that an airplane is protected from the weather before it is moved outside the factory) pushed the left MED plug closed to enable the airplane to be moved outside (based on her reading of the interview transcripts), but, after the timeline for the actions performed by the functional test technician team lead (who partially closed the left MED plug on September 18, 2023) were discussed with her, she agreed that the interviews did not identify who performed the closure of the plug on September 19, 2023.[60]

1.11.2.1.3 Traveled Work Associated with Left Mid Exit Door Plug Area of the Fuselage

A review of the build records for the accident airplane showed that IP "Install [Left] Interior Sidewalls," which involved installing the fuselage interior sidewall panels scheduled for flow day 6, was initiated on September 11, 2023, and short stamped on that same date because the area around the left MED plug could not be completed. Boeing's postaccident review of this IP for the accident airplane showed that it correctly documented which steps were completed (that is, all but the specified area around the left MED plug). The correctly applied short stamp identified the need to reaccomplish all the short-stamped steps in the area around the left MED plug before the final signoff could be applied. IP "Installed [Left] Interior Sidewalls" was completed on September 19, 2023, while the accident airplane was at flow day 10.

As stated in section 1.11.2.1, IP "OK to Install Blankets" was started and short stamped on September 1, 2023, because it had open exceptions to be addressed (notably, the NCR and NCO related to the rivet rework). Boeing's postaccident review of this IP for the accident airplane showed that the application of the short stamp, which was applied to all but the final step, did not clearly define the work remaining.

---

[60] She had previously disclosed, during a June 25, 2024, Boeing media briefing that "we believe the move crew; we know the move crew closed the plug." The NTSB notes that, per 49 *CFR* 831.13, Boeing, as a party to our investigation, was not authorized to release investigative information without our approval; we were neither notified of nor approved the media briefing. As a result of Boeing's unauthorized release of investigative information during the media briefing (and its June 18, 2024, release of information about a different event under investigation), on June 27, 2024, we notified Boeing that we would not tolerate such violations of regulations and the NTSB party agreement and that we would no longer provide Boeing access to the investigative information we continued to produce as we developed the factual record of the accident.

The records showed that IP “OK to Install Blankets” was signed off as completed on September 20, 2023. At that point, the accident airplane’s interior sidewalls had already been installed over the left MED plug.

During a postaccident interview, the Boeing quality assurance inspector who applied the final quality assurance signoff of IP “OK to Install Blankets” on September 20, 2023, stated that her signoff did not involve looking at the airplane but rather verifying that all the steps on the IP related to the rivet rework had been signed off.

She stated that (given what was known postaccident that the left MED plug had been opened without a removal record) the correct process for when the rivet rework NCR and NCO were created would have involved assigning a Boeing quality assurance inspector to verify whether the rework required a removal and, if so, verify that a removal record was attached to the NCO.

1.11.2.2 Manufacturing Personnel at Boeing Commercial Airplanes’ Renton Facility

1.11.2.2.1 Door Team Personnel

During September 2023 (when the accident airplane was in production), one Boeing door manager supervised the 24 Boeing 737 door team personnel who performed the work on the various types of doors (cabin, cargo, exit, access, equipment bay, and others) and MED plugs. According to a door master lead, for MED plugs, routine tasks for door personnel involved performing gap and fit checks on the plug exterior, and no tasks involved the interior side of the plug.

Door team members also routinely set up and performed some functional and operational tests and performed troubleshooting for all door systems. Any work needed for MED plug-related issues would also be assigned to the door team. According to the most experienced door team member (a door crew member), when the need for work was identified, whoever identified it (for example, an interiors manager) would notify the door manager, and the door manager would assign the work directly or through a door team lead.

Door team personnel consisted of the “door crew” and the “door masters.” The door crew covered work for flow days 1, 2, and 3, and door masters covered the work for flow days 7 and 9 and the ramp areas outside of the factory. Personnel from both teams worked the first shift Monday through Friday and assisted with door-related work throughout the factory and preflight.

The door manager’s responsibilities included prioritizing, scheduling, and assigning work. These responsibilities included making daily plans with door team leads, discussing metrics, and helping resolve any issues adversely affecting a team's ability to accomplish its work.

The door manager participated in daily meetings with many levels of Boeing 737 manufacturing leadership to facilitate production efficiency, reviewed open jobs, addressed requests for assistance throughout the Boeing 737 production factory and ramp areas, and participated in Gemba walks and tool kit audits.[61] The door manager oversaw improvement changes in safety and quality (identified and resolved issues), focused on cross training, and ensured the team and work areas were in compliance.

1.11.2.2.2 Manufacturing Workforce Training

According to Boeing's vice president for manufacturing and safety, Boeing provided newly hired Boeing 737 production line employees with initial foundational training that required proficiency checks before new employees would be released to receive on-the-job training on the job series for which they were hired. Job-specific training, such as that required of Boeing 737 door team members, was typically provided on the job, and the training was focused on performing the routine tasks required for every build.

At the time that the accident airplane was in production at Boeing's Renton facility, Boeing required no task list, grading structure, or training documentation for the on-the-job training performed by Boeing 737 door team members. According to information obtained during interviews with five Boeing door team personnel, Boeing relied on the expertise of more experienced personnel to train less experienced workers on the job.

The most experienced door team member (a member of the door crew) had about 25 years' experience working with Boeing 737 doors. He stated that he routinely worked on the jobs assigned to him, provided guidance when others requested his advice, and provided on-the-job training to others. He stated that he believed that he was the only person proficient in working all the Boeing 737 door types, including MED plugs, because the job tasks were specialized such that an individual door team member did not typically work on all door types. (He said that he had worked on them all because he had been with the company for so long.) He stated that he learned how to open and close MED plugs by referring to the rig

[61] Gemba is a Japanese term that in the business process context means to go where the work is done. During Gemba walks on the Boeing 737 production line, leaders walk the factory floor to understand the current state, interact and coach, build a cooperative atmosphere by listening and reflecting on actions needed, reinforce principles and practices, and provide support. The walks can address a specific area of concern by leadership or the team and can include bringing together support roles (such as engineering) on the floor in a specific work area.

document and that he had shown one, possibly two, other door team members how to open and close an MED plug.

He said that the fuselages arrived at the Renton facility with the MED plugs installed and that there was no part of the routine airplane build process that would require opening an MED plug unless there was a problem that needed to be addressed. Two other door team members interviewed stated that, during their routine work, they never had a reason to touch an MED plug because the fuselages arrived at the facility with the MED plug structures fully installed.

The most experienced door team member said that the need to open an MED plug did not arise very often but, when it did, such work was typically assigned to him and that he would generate a removal record.[62] He said that the person performing the work typically generated the removal record, not a manager, but that sometimes a team lead may do it. He said that he was on leave September 18 and 19, 2024 (when the accident airplane's left MED plug was opened).

The other four Boeing 737 door team members interviewed confirmed that this experienced team member was the most knowledgeable on all the doors and was relied upon to provide direction when needed. When asked about any formal training, one door team member stated that the training consisted of shadowing another person on the job for a few months to gain hands-on experience working with specific door types. Each of these door team members had less than 2 years' experience with Boeing 737 doors at the time the accident airplane was in production at the Renton facility.[63] None of the four lesser experienced door team personnel (one of whom was a door master team lead) interviewed had ever opened an MED plug.

[62] A January 2024 review of Boeing CMES records found that, since the first production installation of MED plugs on a Boeing 737 airplane in 2018, there were 62 instances (involving 28 airplanes) of documentation generated for the opening or full removal of an MED plug during the production process, mostly for enabling access to facilitate other work. For each instance, NCRs, NCOs, and removal records were created in accordance with BPI "Perform Part or Assembly Removal." Twenty-four instances (involving 15 airplanes) were initiated on airplanes while in production in Boeing's Renton facility, and 38 instances (involving 13 airplanes) were initiated in field locations after factory rollout, at preflight, delivery center, or storage site locations. Most of the Renton instances occurred before 2021, with one affected airplane in the factory in 2021, two in 2022, and four in 2023 before the accident airplane was in production. About that time (which was after the height of the pandemic production slowdown), Boeing's Renton facility produced about 30 to 38 Boeing 737 airplanes per month (see next section for more information).

[63] Of the lesser experienced employees, two had about 18 months' experience, one had about 21 months' experience, and one had about 23 months' experience with Boeing 737 doors. One had 15 years total experience at Boeing.

Before 2020, Boeing's initial training course provided removal process training to Boeing 737 manufacturing and quality personnel and others. In 2020, Boeing developed an updated removal process training course for all employees who used both Boeing BPI "Perform Part or Assembly Removal" and CMES (which included Boeing 737 manufacturing and quality personnel). Boeing used an ongoing process to determine courses that would be assigned to individual employees based on their responsibilities. All Boeing 737 manufacturing and quality personnel completed the updated removal training course in the years it was assigned, which included 2020 and 2022.

All of the door team personnel interviewed had generated removal records before, with the least experienced door team member stating that he had done it "once or twice" and that it was his understanding that, generally, any time hardware was removed from an installation, a removal record was required.

1.11.2.2.3 Production and Workforce Experience Changes Since 2018

According to Boeing company executives interviewed, in 2018 and 2019, following two fatal accidents involving Boeing 737 MAX airplanes, the company significantly decreased production of the airplane.[64] This required reallocating personnel and halting the hiring process, including not replacing personnel lost through attrition. In 2020, the global pandemic resulted in further workforce reductions, particularly among retirement-eligible employees (who generally had longevity with the company).

In 2022, Boeing sought to increase production to pre-2018 levels and increased hiring to compensate for the employees lost. During that time, Boeing hired people, many of whom had no previous manufacturing experience.

According to Boeing's senior vice president of quality, due to this increase in hiring over a few years, "our workforce changed then because…[of] the quantity of employees we hired, and…the [reduced] number of our employees coming to us with previous aerospace experience." She stated that, traditionally, employees came to Boeing with previous aerospace experience gained from working for suppliers, military bases, airlines, and FAA-certified maintenance, repair, and overhaul facilities but that, "after COVID with this rapid hiring, we got more and more people with no

[64] (a) Before 2018, Boeing produced about 52 airplanes per month from its Boeing 737 production line. During the height of the pandemic slowdown after 2020, production was less than 10 airplanes per month but had increased to about 30 to 38 airplanes per month before the accident. (b) The executives interviewed were Boeing's vice president and general manager, senior vice president of quality, vice president of the Boeing 787 program (who was the vice president for total quality at the time the accident airplane was in production), vice president of manufacturing and safety, senior director of quality for the Boeing 737 program, and vice president and general manager of the Boeing 737 program.

aerospace experience whatsoever." When asked if Boeing had conducted a change management or safety risk assessment on the workforce changes, she stated that she was not aware of such an assessment being done but that, by early 2023, reports from more experienced workers were indicating that the newer employees needed more training.

According to the vice president and general manager for the Boeing 737 program, "…10 years ago, we were closer to 50% of employees with more than 10 years' [experience]. Today, I would say we are at 25 or 30%..., certainly a shift in… tremendous experience level."

Interviews with some Boeing 737 production line personnel indicated that some also reported concerns about decreasing experience levels among manufacturing personnel, what they perceived as deficient training, and issues that result from manpower shortages.

1.11.2.3 Boeing Commercial Airplanes' Oversight Processes for Quality, Safety, and Compliance

1.11.2.3.1 Quality Management System

Boeing's quality management system (QMS) for its commercial airplane production was overseen by its total quality team. The organization was divided into four functional groups: core quality, airplane program quality, supplier quality, and delivery centers. Boeing's QMS was defined in its quality manual, revision 1, dated June 26, 2023, and approved by the Federal Aviation Administration (FAA).[65]

According to the quality manual, the QMS was "the organizational structure, processes, procedures, records, and resources needed to integrate, document, implement, and maintain the various components of an effective business system…." The QMS was intended to ensure that each product that was presented for airworthiness certification met its approved design and was in a condition that was safe for operation.

The QMS covered the 14 *CFR* 21.137 quality system requirements, which include requirements for manufacturing process control, inspecting and testing; design data control; document control; supplier control; inspection, measuring, and test equipment control; inspection and test status; nonconforming product and article control; corrective and preventive actions; handling and storage; control of quality records; internal audits; in-service feedback; and quality escapes.

---

[65] Title 14 *CFR* 21.135, 21.137, and 21.138 established the requirements for a production certificate holder's quality system and quality manual describing that system.

A quality escape was a product that did not conform to its approved design but was released from Boeing's quality system. Boeing's quality manual described how to identify, control, document, and disposition a product that did not conform to specifications, regardless of whether the nonconforming product or service was generated internally, received from an external provider, or identified by the customer.

According to Boeing executives interviewed, Boeing used key performance indicators (KPIs) to measure the health of the Boeing 737 production line. Multiple tiers of Boeing leadership routinely assessed quality control metrics, such as nonconformances, supplier conformance, how long an airplane took to progress through the build, quality escapes, and regulatory compliance issues.

Boeing's QMS was externally audited by the FAA in June 2023, in accordance with a 24-month requirement stipulated in FAA Order 8120.23A, "Certificate Management of Production Approval Holders," and internally audited per Boeing's quality manual.[66] Boeing's QMS manual specified requirements for Boeing to ensure that each supplier-provided product conformed to Boeing's requirements. It specified that Boeing suppliers were managed by Boeing's supply chain organization and were required to have an approved QMS. As suppliers to Boeing, Spirit AeroSystems employees and contractors in Boeing's Renton facility were required to perform all work in compliance with Boeing's QMS. (For example, Boeing had authority to request the rivet rework on the accident airplane because its QMS governed the work performed its Renton facility.)

1.11.2.3.2 Voluntary Safety Management System

According to the FAA, a safety management system (SMS) is "the formal, top-down, organization-wide approach to managing safety risk and assuring the effectiveness of safety risk controls. It includes systematic procedures, practices, and policies for the management of safety risk" (FAA 2024c).

At the time of the accident airplane's production, there was no Part 21 regulatory requirement for Boeing to have an SMS.[67] However, in December 2015,

---

[66] FAA Order 8120.23A (which was effective when the accident airplane's fuselage was manufactured) defined the components of the certificate management program. FAA Order 8120.23A Change 1 was effective on October 27, 2023.

[67] (a) On April 26, 2024, the FAA published its final rule requiring production certificate holders to implement SMS, effective May 28, 2024, with most organizations, including Boeing, required to comply within 36 months. FAA personnel assigned to Boeing expressed no concerns about the company's ability to implement its regulatory SMS in the specified timeline. (b) The SMS final rule was responsive to a Congressional statutory mandate (in division 5, section 102 of the Consolidated Appropriations Act, 2021), recommendations from two aviation rulemaking committees, and, in part,

the FAA had required Boeing to create an SMS as part of a settlement agreement developed to address multiple alleged quality and certification lapses.[68] At the time of the agreement, Boeing had adopted an SMS plan and agreed that it would follow its SMS manual, which the FAA had reviewed.

In December 2020, the FAA accepted Boeing's voluntary safety management system (VSMS), which became operational in June 2021. According to Boeing's VSMS manual, the program's goal was to identify, assess, and control hazards and mitigate risks based on a thorough understanding of the systems, processes, human factors, and operating environment.

During the investigation, Boeing reported that its VSMS was in place at the enterprise, business, major functions, test, and technology levels and that it had been working toward a 2025 timeframe for full integration on the production line. At the time of the accident, Boeing had not yet fully implemented its VSMS to the Boeing 737 production level but was actively working to integrate SMS principles into its QMS while awaiting the FAA's final rule regarding Part 5 for Part 21 operations, which would provide additional guidance about how to meet regulatory standards for the program.[69] Like a regulatory SMS, Boeing's VSMS structure was composed of four pillars: safety policy, safety risk management (SRM), safety assurance, and safety promotion.

None of the FAA inspectors interviewed during this investigation had yet received any training on providing oversight of an SMS, and none had performed an audit specifically of Boeing's VSMS. According to an FAA manager, there was no guidance for providing oversight of a non-regulatory program.[70]

Safety Policy

NTSB Safety Recommendation A-21-48, which asked the FAA to require organizations that design, manufacture, and maintain aircraft to establish an SMS. (c) Title 14 *CFR* Part 21 outlines the processes and standards for certifying aircraft, associated products, components, and equipment, along with the organizations responsible for their design and manufacturing. The regulation covers three primary certification categories: type, production, and airworthiness.

[68] The settlement agreement, which also required Boeing to adopt a regulatory compliance plan and implement an internal auditing system for its organization designation authorization unit, among other activities, was entered into by the FAA and Boeing to resolve allegations documented in 13 FAA enforcement investigative reports.

[69] The FAA had previously developed SMS implementation guidance for aircraft operators, but such guidance did not yet exist for production approval holders.

[70] The FAA inspector (who was interviewed before the FAA's April 2024 final rule for SMS was issued), anticipated that his team would become fully involved in overseeing Boeing's SMS once the final rule is issued, and they are provided policy and guidance for performing SMS oversight.

As part of SMS safety policy, an organization's senior management establishes the policies and processes for the organization to meet its safety goals, to include building upon existing processes and procedures (FAA 2024c). Establishing safety policy sets the tone for how the organization's culture could be, and communications, as part of the SMS structure, are essential in showcasing the organization's commitment to its safety goals.

Boeing's VSMS policy, which was signed by its executive leadership, included its commitment to fostering a positive safety culture; promoting a just culture; eliminating or mitigating potential safety, quality, and compliance risks; and driving continuous improvement.[71]

Safety Risk Management

SRM involves identifying hazards, assessing risks, and implementing and monitoring the effectiveness of controls (FAA 2024c). The goal of this pillar is to ensure that risks are effectively managed and resources are appropriately allocated. Boeing executives interviewed reported that a safety risk assessment would be conducted when any of the triggers of SRM were identified, citing such examples as a new system, change to an existing system, new operational procedure, or ineffective risk control. They described that the triggers might be identified in a variety of ways, including but not limited to the following: planning directives, changes to procedure or process documents, employee reports, leadership identification, or hazards identified from information provided by customers.

When a potential hazard was identified, Boeing used SRM to identify causes, consequences, and risk controls. Boeing would select the appropriate tool for each assessment based on the complexity of the hazard and identify the risk mitigation actions and monitoring necessary to achieve the target risk.

For example, according to Boeing's senior vice president of quality, in June 2023, Boeing initiated an SRM activity titled, "Removals," based, in part, on data indicating recurring issues with the BPI "Performing a Part or Assembly Removal." The SRM activity was ongoing at the time of the accident (see section 1.12.2.3 for more information). The Senior Vice President of Quality also stated there was an SRM activity in progress related to training efficacy, based, in part, on feedback received through Speak Up reports from manufacturing personnel (particularly the more

[71] Just culture has been described as "an atmosphere of trust in which people are encouraged, even rewarded, for providing essential safety-related information" (Reason 1997). A just culture treats people fairly for honest mistakes and errors with a focus on learning how to prevent those errors from happening again. It instills and atmosphere of trust in which people are encouraged to provide essential safety-related information but also clearly defines the line between acceptable and unacceptable behavior (SKYbrary n.d., "Just Culture").

experienced employees) both before and immediately after the accident indicating that the newer employees needed more training.

Safety Assurance

Safety assurance in SMS monitors and evaluates the effectiveness of SMS and makes sure an organization is meeting its safety goals (FAA 2024c). As part of its VSMS, Boeing implemented target monitoring plans to ensure corrective actions improved risk controls and mitigated identified risks.[72] Also, as stated previously, Boeing also conducted continuous monitoring of KPIs as part of its QMS to determine whether unfavorable trends were being detected. If a trend was detected, a risk assessment was conducted to identify whether new hazards had been introduced and additional corrective action was necessary. At the time of the accident, Boeing's efforts to integrate safety assurance components, like those within its VSMS, into its QMS were in progress.

For example, according to Boeing executives interviewed, the company was new to applying SRM to hazard and risk identification under the SMS construct but routinely applied a modified risk assessment to its rate readiness review process. Boeing's rate readiness review process performed reviews to (1) analyze the health of the production system; (2) establish a baseline schedule for the proposed rate change; (3) identify all impacted elements, stakeholders, and requirements; and (4) assess the risks associated with the production rate change.

Safety Promotion

The safety promotion aspect of SMS is focused on the communications, training, and behaviors necessary to ensure a positive safety culture (FAA 2024c). As stated in section 1.11.2.1.2, after the accident, the NTSB interviewed Boeing 737 production line personnel. Fifteen of those interviewed represented various Boeing manufacturing, quality assurance, and front-line managers, as well as some Spirit AeroSystems contractors. Of these personnel interviewed, none were able to articulate what an SMS was or what Boeing's safety policy dictated. Most of these personnel associated "safety culture" with maintaining occupational safety and health standards.

Most of the Boeing 737 production line personnel interviewed reported being familiar with different aspects of Boeing's formal feedback process, to include the Speak Up program, its predecessor called SHEAR, and with filing ethics reports. Few reported that they had ever used the programs; most of the personnel interviewed reported they were comfortable going to their managers to voice concerns, but a few

[72] A corrective action is any set of actions taken to rectify or change a process that caused errors or nonconformance issues.

also expressed some uncertainty their reports would yield any results and some apprehension that the report would reflect negatively on them.

Several production line personnel mentioned that there was workplace pressure, but most indicated that they did not consider it undue and noted that the desire to meet a deadline was an inherent part of the day-to-day operation. None stated they were ever pressured to do work that was outside their capabilities.

Generally, interview comments about positive perceptions of the work environment included a sentiment that the front-line manager would be supportive, that there was good communication between personnel, and that they were unwilling to do anything they were unqualified to do. Negative comments included a statement from a manager who said he had some fear of reprisal for reporting issues, a quality assurance technician who felt as though she was disregarded, and a door master team lead who did not have faith in the anonymity of the feedback systems and felt he was subject to reprisal (postaccident) as the company sought to identify which personnel were involved with opening the accident airplane's left MED plug. One Spirit contractor also mentioned contention between Spirit personnel and Boeing personnel over the disposition of aircraft as they came in from the supplier.

1.11.2.3.3 Business Process Instruction "Perform Part or Assembly Removal"

As stated previously, BPI "Perform Part or Assembly Removal" provided the removal record requirements that applied to all Boeing Commercial Airplanes production lines. Per the BPI, the purpose of a removal record was, in part, to ensure that the product was restored according to all applicable engineering requirements; that a record was generated in CMES for previously accepted parts, assemblies, or installations that were subsequently disturbed; and that configuration accountability was confirmed through completed records of all activity accomplished on aircraft parts, assemblies, and installations.

From 2013 to 2023, Boeing substantively revised BPI "Perform Part or Assembly Removal" 11 times as a result of findings from activities such as scheduled periodic reviews, internal reporting and audits, and FAA oversight. At the time that the accident airplane was in production, the BPI was more than 50 pages long and contained several hyperlinks to various other instructions for determining which process was applicable and when it should be followed. It listed more exceptions about when the removal process was not needed than guidance indicating when it was.

Boeing executives interviewed during the investigation provided information indicating that the BPI was unwieldy and complex to use. For example, Boeing's senior vice president of quality stated that the process was complex, and Boeing had tried to make improvements to the process over time. Boeing's vice president of manufacturing for the Boeing 787 program (who was the vice president for total quality at the time the accident airplane was in production) stated that, when Boeing identified issues with lack of adherence to the BPI, the company tried to clarify or add information to address the issue and that, over time, the BPI became increasingly complex.[73]

Regulatory Compliance Issues

Boeing's Regulatory and Quality System Oversight organization managed the process for investigating and addressing compliance issues, including coordinating with the FAA. Corrective actions were subject to acceptance by the FAA and included process and document updates, quality alerts, training updates, and workshops.

Per FAA Orders 1350.14B, "Records Management," and 2150.3C, "FAA Compliance and Enforcement Program," records related to the investigation of rule, regulation, and order violations were destroyed 5 years after closure, but longer retention was authorized, if needed. From 2018 to 2023, BPI "Perform Part or Assembly Removal" was referenced in 16 regulatory compliance issues, consisting of 9 voluntary disclosures (4 from the Boeing 737 production line) and 7 compliance actions (4 from the Boeing 737 production line).[74] The lack of a removal record for the opening of the left MED plug on the accident airplane's fuselage was not among the disclosures or detected actions.

The voluntary disclosures Boeing submitted to the FAA included issues such as an installation with incorrect seat attachment fittings, multiple instances of foreign object debris, loose connectors, use of an unknown torque value on a lug assembly, incorrect rigging of escape slides, and an in-flight separation of a wing panel. The compliance actions the FAA submitted to Boeing included issues such as missing

[73] She stated that a simplification effort had begun in about February or March of 2024 and was ongoing.

[74] Per FAA Order 2150.3C, "FAA Compliance and Enforcement Programs," the FAA's voluntary disclosure program is intended, in part, to incentivize regulated entities to set up and maintain a system of internal compliance audits to improve its ability to identify and correct safety problems. As part of the program, the FAA forgoes enforcement action when it accepts a regulated entity's prompt disclosure of an apparent violation, and the regulated entity rapidly takes action to correct the violation and preclude its recurrence (FAA 2022, 3-2). Also, per the order, a compliance action is the FAA's nonenforcement method to correct unintentional deviations from a regulatory standard arising from flawed systems and procedures, simple mistakes, lack of understanding, or diminished skills. Its purpose is to restore compliance and to identify and correct the underlying causes that led to the deviation (or share safety concerns and recommendations even when there is no deviation) using an open and transparent safety information exchange between FAA personnel and the production approval holder they oversee (FAA 2022, 5-2).

panel "removal documentation," unauthorized removals of fire extinguisher lines, and functional tests completed without removals.

Internal Audit Findings and "Speak Up" Reports

As stated previously, from 2013 to 2023, Boeing substantively revised BPI "Perform Part or Assembly Removal" 11 times due, in part, to findings from scheduled periodic reviews, internal reporting and audits, and FAA oversight.

From 2018 to 2024, Boeing's internal audits across production lines identified various and repeated issues with unauthorized part removals. From the Boeing 737 production line, the audits identified an insufficient review of work instructions that led to unauthorized part removal and ineffective part control (November 2021) and instances where parts were not consistently identified after removal or before installation (October 2022).

From other production lines, the audits identified instances of ineffective internal controls for part removals (May 2021 and February 2024), repeated findings for failure to prevent unauthorized removals (March 2024), inconsistent performance of the removal process and documentation (October 2022 and October 2023), failure to generate a removal record before part removal (October 2023), and an emergent removal record completed with incorrect data (October 2023).

Corrective Actions

From January 2019 to April 2024, Boeing received 35 employee Speak Up reports concerning BPI "Perform Part or Assembly Removal." Twenty-five of these reports were investigated and closed as of April 2024, and 10 remained under investigation at that time. In some cases, SRM tools and processes were used to identify corrective actions.

Boeing used a communication method called "Quality Alerts" to reemphasize process requirements to manufacturing and quality personnel. These alerts were typically sent to affected Boeing employees through company e-mail. The upper right corner of a quality alert contained one of the following labels: "Information Only," "Action Required," or "Read & Response."

From 2020 through 2023, BPI "Perform Part or Assembly Removal" was the subject of 12 quality alerts, as follows:

- 7 quality alerts addressed the documentation requirements for removing parts or assemblies (for example, Quality Alert 2023-0056-AR19 was issued on July 24, 2023, to remind all employees of the documentation requirements for removing parts or assemblies after performing acceptance in CMES).

- 2 quality alerts, one of which was revised and reissued, emphasized part removal and control requirements for supplier articles.
- 2 quality alerts addressed personnel selecting the incorrect removal templates within CMES.

1.11.2.4 Federal Aviation Administration Oversight of Boeing Production Processes

The FAA's Certificate Management Office for Boeing was in Des Moines, Washington. Boeing's production certificate was managed by the System Operation and Oversight Branch (AIR-580), in the Integrated Certificate Management Division (AIR-500). The branch consisted of multiple sections.

The Airplane Oversight Section (AIR-582) included a subsection (AIR-582A) that was responsible for certificate management of Boeing's Renton and Everett, Washington, production and delivery centers. Another subsection (AIR-582B) was responsible for certificate management of Boeing's Charleston, South Carolina, production and delivery centers; this subsection's manager (located in Charleston) was the principal inspector for Boeing. A third subsection (AIR-582C) was responsible for certificate management of Boeing's engineering, organization designation authorization, and production. The Supplier Systems Section (AIR-583) was responsible for certificate management of Boeing's internal and external supply base, including Spirit AeroSystems in Wichita (see figure 19).

At the time that the accident airplane was in production, 23 aviation safety inspectors and 11 aviation safety engineers had certificate management responsibility for Boeing. Five FAA inspectors were assigned to the Boeing 737 production program at the time the accident airplane's fuselage was in the Renton facility.[75]

[75] After the accident, the FAA initiated actions to begin hiring more than 15 inspectors to provide additional oversight of Boeing manufacturing locations and suppliers, among other actions (see section 1.12.1.3).

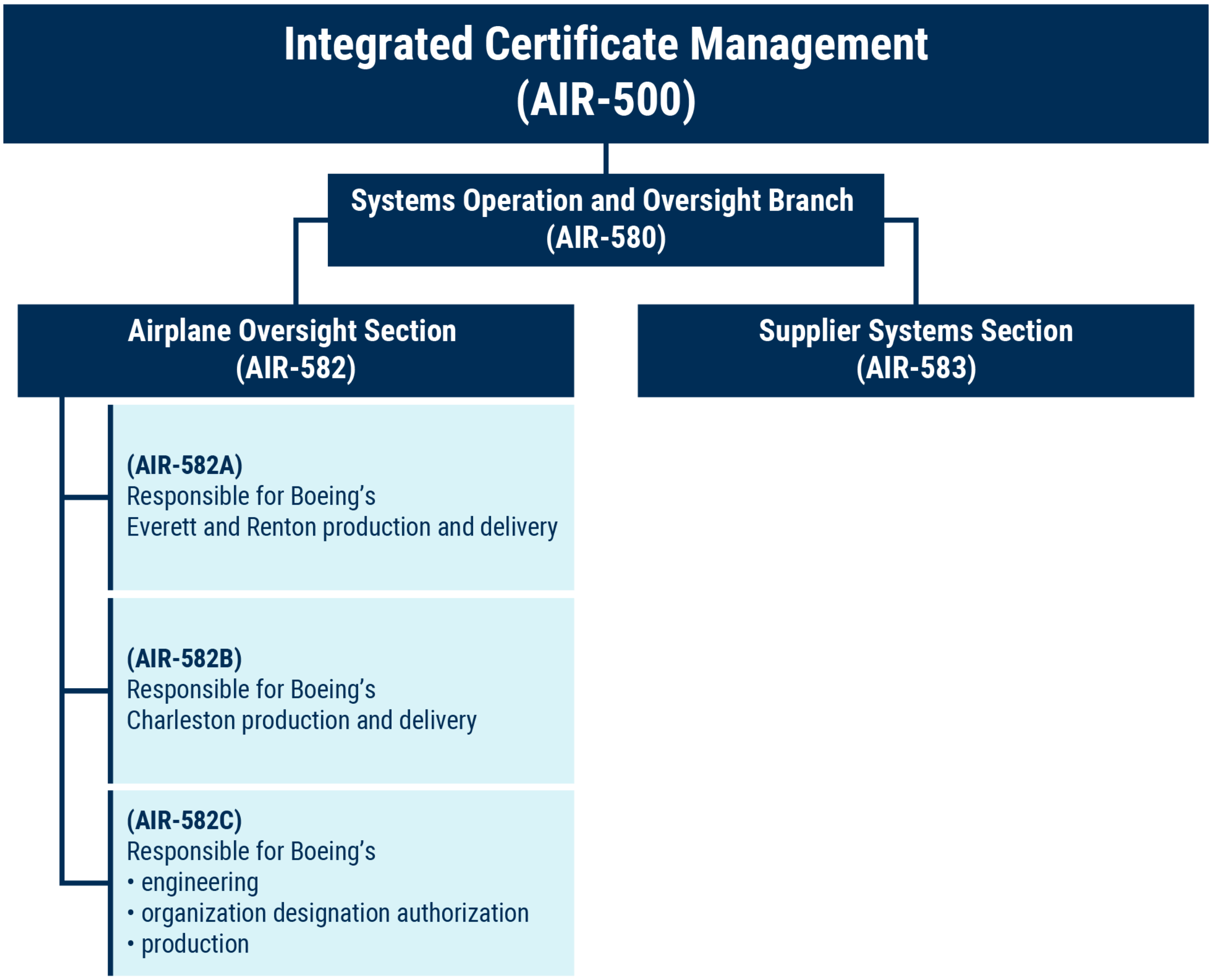


Figure 19. Visual representation of select FAA Certificate Management Office sections and subsections responsible for select aspects of Boeing.

1.11.2.4.1 Certificate Management Program

The FAA's certificate management program is a system-based approach to monitoring a production approval holder's compliance with the regulatory standards for aircraft manufacturing and ensuring corrective actions. The program included the policies, procedures, and associated information technologies with which the FAA fulfilled its statutory responsibilities for ensuring that a production approval holder remained in compliance with applicable regulations. These included 15 quality system elements specified in 14 *CFR* 21.137, which addressed the procedures, documents, records, and data requirements for production approval holders related to design control, document control, manufacturing process control, nonconforming product control, internal audits, and quality escape mitigations, among other areas covered by Boeing's QMS.

Other certificate management responsibilities included auditing and inspecting changes to the quality system, investigating service difficulties that involve quality system problems, and ensuring appropriate corrective actions have been proposed and taken for all compliance issues, among others.

The FAA used a risk-based resource targeting (RBRT) assessment tool to assign a risk level (ranging from 1 to 5 to indicate high, medium, or low risk) to production approval holders as a basis for determining the minimum requirements for the number, frequency, and type of certificate management audits to be performed at each production site annually. The RBRT-derived risk level represented the likelihood that nonconforming products, articles, or parts, would be produced and the consequences associated with introducing those products, articles, or parts into the aviation system. Using this approach, for 2023, the FAA determined Boeing's Renton, Everett, and Charleston production sites were each Level 1, High Risk.[76]

Based on the determined risk level, FAA managers used the aircraft certification audit information system (ACAIS) to develop a certificate management plan for the inspectors. The ACAIS tool tracked the elements specified in FAA Order 8120.23A, and FAA inspectors documented their audit findings in ACAIS.

According to the FAA inspectors interviewed, all were aware that their manager used the RBRT as the basis for developing their planned activities for the year, but none knew how the RBRT identified risk areas for them to focus their activities. One inspector stated that he believed that the RBRT used data, including the result of past audits, from a variety of FAA databases to generate a report for his manager to reference when developing the certificate management plan.

From October 2022 to September 2023, inspectors completed 22 principal inspector audits, 1 quality system audit (a comprehensive system audit), and 53 product audits at the Renton facility. These audits documented 68 alleged noncompliances, which included issues with manufacturing process control (33 alleged noncompliances), document control (10 alleged noncompliances), and quality escapes (4 alleged noncompliances), among others.[77] The ACAIS tool tracked

[76] The RBRT considered criteria such as production volume, number of models in production, number of external suppliers (or percentage of outsourcing) of critical parts or major assemblies, and other rationale considered relevant by the manager of the manufacturing management office. Based on the production volume, number of models, and external supplier criteria alone, these Boeing facilities would always be assigned, Level 1, High Risk.

[77] An FAA surveillance finding is considered alleged until the FAA and Boeing determine a resolution for the finding.

the elements of the principal inspector and quality system audits specified in FAA Order 8120.23A. A review of the 68 alleged noncompliances identified during the audits revealed that none specifically referenced BPI "Perform Part or Assembly Removal."

According to the FAA inspectors, before the accident, their surveillance findings typically consisted of items such as tool and foreign object control violations, routine deviation from work instructions, and training deficiencies. These categories typically generated the most corrective actions and compliance issues. A common training deficiency concerned workers not knowing how to find the manufacturing documents needed for a specific job.

As stated in the previous section, FAA inspectors worked with Boeing's Regulatory and Quality System Oversight to address the 16 regulatory compliance issues related to BPI "Perform Part or Assembly Removal" identified from 2018 to 2023 (9 voluntarily disclosed by Boeing and 7 identified by the FAA).

Also, interviews with FAA inspectors and a retired FAA certificate office manager identified their awareness of a history of issues with the BPI.

1.11.2.4.2 Acceptance of Voluntary Safety Management System

The FAA inspector who served as the SMS program advisor assigned to assist Boeing in developing its VSMS said that Boeing had performed well in developing and implementing its program and that the FAA accepted it because it established the processes and procedures necessary for an SMS. He said that the FAA had witnessed Boeing's execution of those processes and procedures and that the company was actively working toward a mature program.

As stated previously, at the time of the accident airplane's production, there was no regulatory requirement for an SMS. The FAA did not conduct surveillance specific to the program, including Boeing's progress on integrating its VSMS and QMS processes. Most of the FAA inspectors interviewed had not yet attended SMS training to learn what it entailed or what the requirements would be for oversight.

1.11.2.4.3 Supplier Control Audits at Spirit AeroSystems' Facilities

As a production approval holder, Boeing was required (per 14 *CFR* 21.146) to maintain their quality system in compliance with the data and procedures approved for its production certificate, which included ensuring that the completed product conformed to its approved design.

The FAA conducted supplier control audits at Spirit AeroSystems' facilities to evaluate Boeing's ability to impart its quality system control to Spirit and the products and articles it produced or supplied. (Supplier control audits are not audits of the supplier itself.)

From October 2022 to September 2023, the FAA conducted 16 supplier control audits at Spirit AeroSystems' facilities, including 12 audits at the facility in Wichita, 2 in Tulsa, 1 in Malaysia, and 1 in Europe. During this same time, 32 product audits were conducted at Spirit AeroSystems. The audits consisted of quality elements in manufacturing process control and supplier control.

Twenty-seven alleged compliance issues were documented relating to various quality procedures not being followed. Boeing developed corrective action plans to address the identified issues, and the FAA monitored Boeing's progress through regular meetings and correspondence.

1.12 Additional Information: Postaccident Safety Actions

1.12.1 Federal Aviation Administration

1.12.1.1 Emergency Airworthiness Directive for Mid Exit Door Plug Inspections

Based on the preliminary investigative findings for this accident, on January 6, 2024, the FAA issued Emergency AD 2024-02-51 to prohibit the further flight of all Boeing 737-9 airplanes until the MED plugs were inspected and any discrepancies corrected using an FAA-approved method. Boeing worked with the FAA to develop a multi-operator message (MOM), MOM-MOM-24-0010-01B(R4), which provided approved inspection instructions.

The inspections required by Emergency AD 2024-02-51, which affected 171 Boeing 737-9 airplanes, were completed by January 31, 2024, for all but 4 airplanes, 2 of which were undergoing heavy maintenance at the time and had the inspections completed by February 14, 2024.[78] For each inspected airplane, the MED plugs were found to be engaged with the fuselage stop fittings and with the two upper guide track bolts and the two vertical movement arrestor bolts installed.

To address MED plug inspections for in-production, MED plug-equipped airplanes, on March 1, 2024, the FAA approved a Boeing NCR that would serve as a method of compliance for AD 2024-02-51. The NCR prompted individual NCOs to be

[78] The remaining airplanes were the accident airplane and one other. The accident airplane's right MED plug inspection was completed, but a new left MED plug had not yet been installed. The inspection status of the other airplane (which was configured for executive transport) was unknown because it was subject to US and European Union sanctions that prevented communication with the operator.

initiated for each applicable airplane to inspect the MED plugs in accordance with the MOM previously published for the AD.

On November 4, 2024, the FAA approved two Boeing IPs for in-production, MED plug-equipped airplanes that added an inspection of the left and right MED plugs to ensure that the two upper guide track bolts, two vertical movement arrestor bolts, and two lower hinge pin bolts were installed in accordance with the drawing and in compliance with the AD. Incorporation of the IPs became part of the type design for each airplane.

1.12.1.2 Safety Alert for Operators of Boeing 737-900ER Airplanes

On January 21, 2024, the FAA issued Safety Alert for Operators (SAFO) 24001, which provided information to the operators of Boeing 737-900ER airplanes, which were equipped with MED plugs identical to those installed on Boeing 737-9 airplanes. The SAFO encouraged Boeing 737-900ER operators to conduct a visual inspection to ensure that the MED plug upper guide track bolts and vertical movement arrestor bolts were installed.[79]

1.12.1.3 Increased Oversight of Boeing and Its Suppliers

Other actions taken after the accident included increased on-site FAA inspector presence at Boeing's Renton facility and Spirit AeroSystems' Wichita facility, a halt to the production expansion of Boeing 737 MAX airplanes, and actions to begin hiring more than 15 inspectors to provide additional oversight of Boeing manufacturing locations and suppliers. The enhanced oversight of Boeing and its suppliers included the following:

- Targeted auditing and surveillance of manufacturing and quality activities to conduct oversight of improvement activities.
- Additional auditing at critical points of the production process and involvement in quality and manufacturing daily/weekly activities.
- Monitoring quality system metrics to identify any areas of concern, to include targeting auditing activities [FAA 2024b].

The FAA administrator actively encouraged hotline and whistleblower complaints, and the FAA investigated all of them. The FAA also concluded an audit of Boeing's 737 production line and identified compliance issues in Boeing's

[79] A review of available fleet data indicated that all Boeing 737-900ER airplanes in service had surpassed the MED plug inspection threshold in the maintenance program such that the plugs should have been opened and inspected at least once before the SAFO was issued.

manufacturing process control, parts handling and storage, and product control (FAA 2024b).

In the months after the accident, the FAA communicated with Boeing officials to ensure expectations were met and to provide oversight of changes to the production system. Boeing was required to provide a detailed update on completed actions as well as mid- and long-term actions, including but not limited to:

- Strengthening its VSMS (which must become a regulatory SMS in 2027, per the FAA's final rule), including employee safety reporting.
- Simplifying processes and procedures and clarifying work instructions.
- Enhancing supplier oversight.
- Enhancing employee training and communication.
- Increasing internal audits of production system.
- Improving IPs.

Boeing also had to identify the results of completed actions and how it will monitor those and future actions to validate progress and sustain the changes. The FAA indicated that it was committed to actively monitoring Boeing's progress in various ways, including:

- Having a team of FAA subject matter experts to continually review Boeing's progress and the effectiveness of the changes in addressing the audit findings and expert panel recommendations.
- Having senior FAA leaders meet with Boeing weekly to review performance metrics, progress, and any challenges in implementing the changes (FAA 2024b).

1.12.2 Boeing Commercial Airplanes

1.12.2.1 Multi-Operator Message for Mid Exit Door Plug Inspections

Boeing worked with the FAA to develop MOM-MOM-24-0010-01B(R4), which provided the approved MED plug inspection instructions for the FAA's January 6, 2024, emergency AD 2024-02-51 (as described in section 1.12.1.1).

1.12.2.2 Multi-Operator Message Regarding Flight Crew Operations Manual Update Regarding Flight Deck Door

On January 13, 2024, Boeing issued MOM-MOM-24-0029-01B to inform owners and operators of Boeing 737 MAX airplanes of an update to the Flight Crew

Operations Manual (FCOM) to clarify the expected flight deck door behavior during a rapid depressurization event.

1.12.2.3 Updates to Business Process Instructions, Installation Plans, and On-the-Job Training Related to Parts Removals

As stated in section 1.11.6.2.1, as part of Boeing's VSMS, SRM activity related to BPI "Perform Part or Assembly Removal" that it initiated in June 2023 was ongoing at the time of the accident. Actions Boeing completed by the time of this report included a June 12, 2024, revision to the BPI, release of additional training to emphasize when and why removal documentation was required, and a change to CMES to allow only personnel who had completed the additional training to initiate a removal.

Also, Boeing's postaccident review of all work on the accident airplane associated with IP "OK to Install Blankets" identified that some short stamps did not clearly define the work remaining, removals for blankets were also not documented, and the final operation step was performed and signed off without the inspector redoing any of the inspections specified in the IP, contrary to training. Boeing executives interviewed stated that the company had initiated updates to the associated IPs and BPIs.

Boeing also indicated that, in 2024, it implemented a documented on-the-job training requirement. The on-the-job training required each newly hired Boeing 737 door team member to perform identified tasks and that, for each task, the door team member must witness the task, perform the task with assistance, and perform the task under supervision 10 times.

1.12.2.4 Improvements to Quality Assurance and Safety Management Processes

After the accident, the FAA required Boeing to produce a comprehensive plan for addressing quality assurance and safety management issues, including those in the supply chain. In response, Boeing developed its Product Safety and Quality Plan and submitted it to the FAA's Integrated Review Team.

As part of the plan, Boeing's leadership selected six indicators that they felt best represented quality and safety health. Boeing worked with the FAA to refine these KPIs, which were already part of a larger body of metrics that Boeing monitored under its QMS, to become more risk-focused rather than production-focused. Boeing's SMS policy letter dated March 2025 indicated its commitment to using actional KPI metrics and targets to drive continuous improvement of its SMS.

The six KPIs selected for refinement were (1) employee efficiency, which measures share of employees currently staffed to commercial programs who are proficient; (2) notice of escape rework hours, which measures rework due to fabrication and supplier-provided escapes to final assembly; (3) supplier shortages, which measures fabrication and supplier shortages; (4) rework hours per airplane, which measures total rework hours per airplane in final assembly; (5) traveled work at factory rollout, which measures jobs traveling from final assembly; and (6) ticketing performance, which measures average escapes per ticketed item.

Each KPI had defined criteria to help identify areas of potential risk to its operations and trigger corrective action through SMS risk monitoring. Boeing reported that these critical, safety-focused metrics will enable continuous assessment of production system health and serve as an early warning of emerging quality and safety risks. According to a Boeing web page, "each KPI has defined criteria that help identify areas of potential risk to our operations and trigger corrective action through our [SMS]. These metrics have helped Boeing conduct more targeted safety risk assessments in priority areas and maintain production health" (Boeing n.d., "Strengthening Safety & Quality").

Boeing also conducted a comprehensive review of its supply chain, quality system, and production system, and completed the following safety actions:

- Held quality stand-downs at every major facility for its commercial airplanes, with more than 70,000 employees participating to share their perspectives on improving safety, quality, and compliance;
- Revised the build plans, training, maintenance planning, aircraft manual documentation, removal requirements, and inspection criteria for MED plugs;
- Initiated additional controls to prevent defects in MED plugs and similar structures and assemblies;
- Added conformance inspections to nine critical build points. Processed fleet and production inspection findings through its VSMS and QMS;
- Published alerts on removals and rework, signed by all factory employees;
- Implemented easier and more accessible employee reporting through an updated Speak Up reporting tool;
- Instituted additional controls at Spirit AeroSystems to prevent defects in MED plugs and similar structures and assemblies, including new inspections and preshipment approval requirements on fuselages;
- Added competency assessments for all supplier mechanics doing structural work at Boeing sites;

- Issued supplier bulletins to strengthen focus on conformance and reduce the risks of defects being shipped; and

Boeing also implemented a "move ready" process for the Boeing 737 production line that established SMS controls to mitigate risk associated with traveled work. Under the process, airplanes may not move to the next factory position (flow day) until identified build milestones are completed, unless a safety risk assessment is conducted and a mitigation plan is in place. Boeing identified criteria for the critical build milestones for several final assembly positions and has since implemented the move-ready criteria and safety risk assessment process for its Boeing 767, 777, and 787 programs.

1.12.2.5 Mid Exit Door Plug Placard and Revision to Rigging Drawing

Boeing implemented the use of MED plug removal caution placards during the manufacturing process. Boeing also worked with Spirit AeroSystems to complete an October 2024 revision to an MED plug rigging drawing to remove the operational check specified in section 5.2.1, which had stated, "Operate the completed plug and verify that it operates smoothly while clearing all body structure."[80]

The revision resulted from Boeing's postaccident review of documents that identified that no Boeing 737 IP contained the operational check listed on the drawing. Boeing subsequently determined (and documented through an associated NCR and NCO) that it was acceptable to omit the MED plug operational check because it was not possible to perform such a check when the MED plug was in its final installed state. Boeing engineering reviewed previously completed rigging verifications that had omitted the operational check and determined that no rework was required.

1.12.2.6 Oxygen Canister Pad Retrofit Actions

As stated in section 1.10.3, all the chemical oxygen generators on board the accident airplane that were equipped with flat pads under the retention straps were found to be displaced aft from their installed positioned. Boeing found that the pressure-sensitive adhesive on this type of pad had failed, allowing the oxygen generators to shift position.

In December 2023 (after receiving reports from an operator that identified displaced canisters on two in-service airplanes that year), Boeing ceased using the flat pads on new production airplanes in favor of pads that did not rely on pressure-sensitive adhesive. In April 2024, Boeing issued two MOMs to advise operators of Boeing 737 MAX and NG airplanes of the draft service bulletins related

[80] Spirit AeroSystems designed the MED plug and had drawing responsibility for the design.

to inspecting in-service airplanes and retrofitting them, as applicable, with the appropriate pads.

On June 17, 2024, Boeing issued MOM-MOM-24-0316-01B and Boeing special attention requirements bulletins 737-35-1210 RB and -1211 RB to Boeing 737 MAX and NG operators. On June 18, 2024, Boeing created temporary revisions of the respective aircraft maintenance manuals then fully incorporated them into the September 15, 2024, aircraft maintenance manual revision cycle. On July 25, 2024, the FAA issued AD 2024-13-02 to require the actions identified in the two Boeing special attention requirements bulletins.

1.12.2.7 Ongoing Work on Mid Exit Door Plug Design Enhancement Certification

After the accident, Boeing worked with Spirit AeroSystems (which owned the MED plug engineering design) to develop a design enhancement to add two secondary retention devices to prevent an MED plug from moving upward in the event that the vertical movement arrestor bolts and upper guide track bolts were not installed. The retention devices would also prevent the sidewall panels from being installed unless the devices were engaged. The design enhancement also added lanyards to the vertical movement arrestor bolts and upper guide track bolts so that they would remain hanging on the frame or plug when removed, providing a visual indication when the bolts were not installed.

According to correspondence from Boeing in May 2025, the development of the design enhancement was completed, and Boeing and Spirit were continuing certification planning and compliance work, which will require notifying the FAA. Boeing estimated that the design enhancement, once certified, would be incorporated on all applicable new production airplanes likely sometime in 2026. Boeing intended to release a service bulletin to address retrofits for in-service airplanes.

1.12.3 Spirit AeroSystems

1.12.3.1 Corrective Action for Mid Exit Door Plug Seal Lubricant

On January 17, 2024, the investigative group observed a Spirit AeroSystems installation mechanic use petroleum jelly to lubricate the MED plug seal area to assist in closure during installation, and, as stated in section 1.10.1.1, petroleum jelly residue was identified on the MED plug seals on the accident airplane. According to an engineering drawing note, the use of dish soap was allowed for such purposes. Spirit provided an engineering evaluation that stated that the petroleum jelly would not negatively affect the components, but, on February 1, 2024, generated an NCR to document the process discrepancy. Corrective actions included removing and cleaning the petroleum jelly from the seal area and reinstalling the seal using the appropriate liquid lubricant per Boeing specifications. Spirit AeroSystems notified Boeing of the process discrepancy.

1.12.3.2 Supplier Production Process Review

Spirit AeroSystems initiated a supplier production process review (for Quik Tek, the rivet installer) related to the rivet workmanship issues identified on the accident airplane, which included performing inspections of both installed and in-stock fuselage door edge frame assemblies. On March 5, 2024, Spirit generated a supplier activity report to document the review process and the resolution of an identified issue (which was unrelated to the conditions identified on the accident airplane).

1.12.3.3 Quality Improvement Plan and Other Actions

In the third quarter of 2023, Spirit AeroSystems instituted a multi-phased, comprehensive Boeing 737 quality improvement plan after allowing fuselages with undetected nonconformances to be delivered to Boeing. After the accident, Spirit AeroSystems expanded the plan and completed the following actions:

- Added inspection points on MED plugs.
- Replicated the inspections documented by Boeing MOM-MOM-24-0010-01B(R4).
- Changed manufacturing planning build validation for MED plugs to ensure the upper guide track bolts and vertical movement arrestor bolts have been installed correctly per procedures.
- Jointly performed safety management risk assessments with Boeing, which identified and prioritized critical IPs to incorporate mitigating actions.
- Targeted employee communications with Boeing customer messaging.
- Received and analyzed regulatory and Boeing audit data and airline customer feedback to improve the QMS.
- Implemented final product acceptance jointly with Boeing to improve quality and reduce traveled work.

Before the accident, Spirit AeroSystems had voluntarily implemented the fundamentals of an SMS throughout the company and performed a focused assessment of the skills, performance, and training of its production, audit, and inspection personnel. Since the accident, Spirit's SMS was accepted by the FAA. Spirit also conducted a focused assessment of the skills, performance, and training of production, audit, and inspection personnel.

1.12.4 Alaska Airlines

1.12.4.1 Fleet Inspections

As a precaution, immediately after the accident, Alaska Airlines grounded its fleet of Boeing 737-9 airplanes to inspect the MED plugs. (The FAA emergency AD requiring inspections was issued the next day.) It completed the inspections before returning those airplanes to service in late January 2024. It also inspected all MED plugs on its Boeing 737-900ER airplanes.

1.12.4.2 Engagement with Boeing for Oversight of In-Production Airplanes

Alaska Airlines engaged with Boeing leadership to understand its plans for addressing quality assurance, including such activities as reviewing Boeing's production and quality control systems and manufacturing improvement plans and providing feedback and monitoring Boeing's execution of those plans. The airline also enhanced its on-site inspection program for in-production Alaska Airlines aircraft and its intake inspections of newly delivered Boeing airplanes.

1.12.4.3 Flight and Cabin Crew Manuals and Training Updates

Alaska Airlines updated its Boeing 737 MAX systems handbook to clarify the expected flight deck door behavior during a rapid depressurization event, based on Boeing's FCOM revision, and added the information to pilot training. The airline also updated the FAM and flight attendant initial and recurrent training to include flight deck door information.

The airline also updated company manuals and issued an illustrated flight training bulletin to help ensure that flight crews understand the differences between the Boeing 737 NG and MAX oxygen systems. Pilot training and checking events were updated to emphasize the Boeing 737 MAX procedures for donning and removing the oxygen mask and reestablishing boom microphone communications. This included providing hands-on training during continuous qualification and line-oriented flight training simulator events.

Other procedural, manual, and training updates addressed various topics, including CVR data retention procedures (discussed in the next section), crew communications, and the flight attendants' use of cabin oxygen masks and portable oxygen bottles. This included updated flight attendant initial and recurrent training to highlight the need to obtain oxygen and secure themselves immediately while assessing a depressurization event and establishing communication; to describe that the cabin mask-to-mask procedure was to be used only immediately after a depressurization to reach the closest passenger seat, jump seat, or portable oxygen bottle; and to provide a demonstration on how to remove and don a portable oxygen bottle mask similar to the mask type used on the accident flight.

1.12.4.4 Cockpit Voice Recorder Circuit Breaker Procedures and Checklist Improvements

Following the accident, Alaska Airlines implemented several changes related to preserving FDR and CVR data after an incident or accident, as follows:

- Added CVR circuit breaker information to the QRH;
- Added a reminder to the flight operations duty officer and dispatch brief checklists to confirm that CVR and FDR circuit breakers are pulled following an event; and
- Revised the Emergency Coordination Center maintenance and engineering checklist, non-Emergency Coordination Center maintenance control checklist, and Emergency Coordination Center flight operations checklist to prioritize timely pulling of the FDR and CVR circuit breakers following an event.

2 Analysis

2.1 Introduction

The airplane experienced an in-flight separation of the left MED plug and rapid depressurization during climb about 6 minutes after takeoff from PDX. Alaska Airlines had taken delivery of the newly manufactured airplane from Boeing about 3 months before the accident.

The analysis first discusses the accident sequence and the airplane's manufacturing history related to the missing bolts. Specifically, we address the following:

- The accident sequence, including the flight and cabin crewmembers' actions in response to the emergency (section 2.2.1), and the evidence that the four bolts that secure the left MED plug from moving vertically were missing before the accident flight (section 2.2.2).
- The airplane's manufacturing history related to the missing bolts, including the opening of the left MED plug at Boeing's Renton facility without the required removal documentation (section 2.3.1), the complexity of Boeing's BPI for parts removals (section 2.3.1.1), the inadequate training of manufacturing personnel (section 2.3.1.2), and the incomplete closure of the plug without the bolts (section 2.3.2).

The safety issues identified in this accident are the following:

- Quality assurance processes and oversight deficiencies, including Boeing's ineffective change management related to workforce experience level decreases (section 2.4.1); and Boeing's ineffective corrective actions and the FAA's ineffective oversight processes that allowed the persistence of issues with Boeing's BPI for parts removals (section 2.4.2).
- The need for Boeing to improve its quality escape mitigation strategies (section 2.4.3) and continue its development and implementation of SMS (2.5).
- Other safety issues, including the need for flight crew hands-on emergency oxygen mask training (section 2.6.1), the need to ensure that the design standards for portable oxygen bottles ensure that the masks are easy to unpackage and use (section 2.6.2), the need for effective operator procedures and 25-hour CVR installations and retrofits to prevent the loss of CVR audio (section 2.5.3), and the safety benefits of using child restraint systems (CRS) for children under the age of 2 years (section 2.6.4).

The investigation's comprehensive review of the circumstances that led to this accident determined that none of the following was a factor:

Alaska Airlines' crew qualifications and airplane maintenance: The flight and cabin crewmembers were certificated and qualified in accordance with applicable federal regulations and Alaska Airlines' requirements. There was no evidence that, since delivery, Alaska Airlines performed any maintenance, inspection, or retrofit work on the airplane that would involve opening the left MED plug.

Flight crew routine preflight walkaround inspection procedures. Based on an examination of the accident airplane's undamaged right MED plug (see section 2.2.2.2 for the supporting analysis), the NTSB determined that the size of the exterior gap associated with the maximum possible upward displacement of an MED plug (before it disengaged from the fuselage frame) was about half an inch larger than the gap when the plug was fully down. Although gap size difference was visually perceivable during the investigation's focused comparison, it was subtle when viewed from the ground. Thus, the NTSB concludes that the evidence of the upward displacement of the left MED plug before the accident flight would not have been readily detectable by a flight crewmember performing a routine preflight walkaround inspection.

Cabin pressurization system and previous cabin pressurization AUTO FAIL light illumination events. A review of the QAR data for the accident flight revealed that the pressurization system was operating per design both before and after the rapid depressurization occurred due to the in-flight separation of the MED plug. No faults or status messages for the accident flight were recorded in the CPCs until after the MED plug separated. Postaccident, on-aircraft testing revealed that both CPCs were configured properly, and the cabin pressurization system passed the performed tests.

Evaluation of the accident airplane's previous cabin pressurization AUTO FAIL light illumination events (none of which occurred during the accident flight) determined that the occurrences (four since airplane delivery) likely resulted from intermittent microchip failures. For each occurrence recorded on the QAR (the two most recent occurrences), the system detected the failure and automatically transferred command to the alternate CPC, as designed. No evidence of any associated cabin pressure control disruption was associated with any of the AUTO FAIL light illumination events. However, it cannot be determined from the available data whether any air leakage associated with the left MED plug's upward displacement during previous flights occurred. This is because it is possible that, if any such leakage occurred, it may not have exceeded the capability of the cabin pressurization system to maintain adequate cabin pressure and, therefore, no cabin pressure control disruption would have been recorded.

Thus, the NTSB concludes that the airplane's cabin pressurization system operated as designed both before and after the left MED plug separated, and there was no evidence that the previous pressurization system AUTO FAIL light illumination events were associated with the left MED plug's upward displacement during previous flights.

2.2 Accident Sequence

2.2.1 Crew Responses to Emergency

2.2.1.1 Flight Crew

The airplane was climbing through about 14,830 ft when the cabin pressure dropped, and the cabin altitude warning activated, followed by the master caution alert. The captain and the first officer immediately retrieved their emergency oxygen masks from their respective stowage boxes and donned them. Even though the QRC was not in its holder (likely having been blown out by the outflow of air from the flight deck), the flight crew performed the first two items from the "CABIN ALTITUDE WARNING or Rapid Depressurization" from memory, as appropriate, before retrieving the QRH to complete the checklist procedures.

The crew declared an emergency with air traffic control, requested a lower altitude, and requested a return to the airport. FDR data showed that the airplane ceased climbing about 1 minute after the depressurization event, began a descent, and was below 10,000 ft less than 5 minutes after the event.

Thus, the NTSB concludes that, the flight crew's immediate actions to don their oxygen masks after the rapid depressurization and use the "CABIN ALTITUDE or Rapid Depressurization" checklist were consistent with company procedures, their decision to descend the airplane and return to the departure airport was timely and appropriate, and they demonstrated effective high-workload management and task allocation appropriate for a two-person crew to safely handle the emergency. The NTSB also concludes that the teamwork and complementary duties of the flight crew, which occurred during the emergency, reinforce the necessity for a minimum crew of two pilots, as specified in the airplane type certificate, as well as Part 121 operating rules.

Due to the loud noise on the flight deck from the rushing air, the captain and the first officer had difficulties communicating. When they donned their oxygen masks, the oxygen mask microphones were automatically selected, but the first officer had difficulty hearing the captain and the air traffic controller over the overhead speaker. The captain tried repeatedly to communicate with the flight attendants over the interphone but was not able to determine whether they could hear him, but, at times, he could hear them discussing a hole in the cabin.

After the airplane was below 10,000 ft, the captain and the first officer tried to establish better communications by putting their headsets back on. After removing their oxygen masks, neither the captain nor the first officer performed the procedure for reestablishing communications to their headset boom microphones, and both were unaware that the oxygen mask microphones were still selected. (The Boeing 737 MAX procedures differed from those of the Boeing 737 NG airplanes. See section 2.6.1 for more information.)

As a result, the noise coming through their headsets (from the oxygen mask microphones) made it impossible for them to hear each other or air traffic control. Thus, they decided to resume using their oxygen masks for the remainder of the flight, which enabled continued communications. The NTSB concludes that, although the flight crew did not perform the procedures to switch communications back to their headsets after removing their oxygen masks, this had no adverse effect on their subsequent safe landing of the airplane.

2.2.1.2 Cabin Crew

Before the event, flight attendant D got up from her seat and had just unlocked the forward lavatory door. When the rapid depressurization occurred, the flight deck door opened forcefully and struck her. She sat back down, held onto her seat restraint, and struggled to close the flight deck door but was eventually successful.

Neither the cabin crew nor the flight crew was aware that the flight deck door would open during a rapid depressurization event. After the accident, Boeing issued a MOM to all Boeing 737 MAX customers to update the FCOM to include expected flight deck door behavior, and Alaska Airlines updated its flight and cabin crew manuals, procedures, and training to include this information.

As soon as the depressurization occurred, all four flight attendants immediately donned their overhead oxygen masks, and a prerecorded, automated depressurization announcement played in the cabin in both English and Spanish to inform passengers and flight attendants to put on their oxygen masks, remain seated, and ensure their seat belts were fastened.

The flight attendants faced challenges trying to communicate with the flight crew and each other due to the loud noise in the cabin from the rushing air. Flight attendant A repeatedly attempted to communicate with the flight deck via the interphone but was uncertain whether the flight crew could hear him, and he received no communications from the flight crew until he heard (faintly over the interphone) one pilot say that the flight was returning to the airport. Flight attendant A relayed this information to the other flight attendants and made an announcement for the passengers.

Flight attendants C, D, and B used supplemental oxygen sources to move through the cabin to check on unaccompanied minors and other passengers. Flight attendant C used the mask-to-mask procedure (breathing by using the extra oxygen masks hanging from the passenger service units in the cabin) to move forward through the cabin; however she described this method as challenging because she could not reach the spare mask at each row (because they were located too far outboard, as seen in figure 9), passengers didn't understand that she needed them to hand her the mask, and some masks were entangled with others.

In addition, flight attendants D and B, who used the portable oxygen bottles, each reported challenges opening and donning the mask; however, both flight attendants successfully used the portable oxygen bottles to obtain oxygen and move through the cabin.

Thus, the NTSB concludes that flight attendant A's difficulty communicating with the flight crew and challenges communicating with the other cabin crewmembers did not impede the cabin crew's ability to execute cabin procedures and effectively ensure the safety of the passengers, including unaccompanied minors, after the rapid depressurization and during the descent and return to the airport.

Further, the NTSB concludes that all flight attendants and passengers were able to use the overhead oxygen masks to obtain oxygen after the rapid depressurization, and the portable oxygen bottles provided oxygen to the two flight attendants who used them to move through the cabin.

After the accident, Alaska Airlines updated its FAM, initial training, and recurrent training to include cabin crew procedures for communicating with flight crew during a depressurization event.

The airline also updated its flight attendant initial and recurrent training to highlight the need to obtain oxygen; to describe that the cabin mask-to-mask procedure was to be used only immediately after a depressurization to reach the closest passenger seat, jump seat, or portable oxygen bottle; and to provide a demonstration on how to remove and don a portable oxygen bottle mask similar to the mask type used on the accident flight. However, the NTSB is concerned about the difficulties that the flight attendants encountered when using the portable oxygen bottles (see section 2.6.2).

2.2.2 Evidence of Missing Left Mid Exit Door Plug Bolts

On a Boeing 737-9 MED plug installation, the plug is prevented from moving outboard from the fuselage door frame by 12 plug stop fittings, 6 each on the forward and aft sides of the plug, that are aligned inboard of the frame stop pads. For a plug to move outboard, it first has to move vertically upward enough for its stop fittings to clear the frame stop pads. On a normal MED plug installation, plug vertical movement is prevented by four bolts: two vertical movement arrestor bolts and two upper guide track bolts.

Based on a Boeing engineering review, the presence of only one vertical movement arrestor bolt (with the other three bolts missing) would preclude upward movement of an MED plug, or the presence of only the two upper guide track bolts (with the vertical movement arrestor bolts missing) would prevent the plug from moving upward the distance needed for the stop pins to clear the stop pads.

However, none of the four bolts were present in the left MED plug components recovered from the accident airplane. Further, the NTSB Materials Laboratory's examination of these components identified the presence of damage patterns consistent with vertical upward and outboard movement of the plug, as well as the absence of bolt contact damage on the bolt holes for all four bolts (described below).

2.2.2.1 Damage Consistent with Plug Upward and Outboard Movement

For the left MED plug, all 12 plug stop fittings and frame stop pads were intact. However, sliding contact marks were observed on the lower sides of the plug stop fittings, and corresponding sliding contact damage was observed on the upper sides of the frame stop pads. This damage pattern was consistent with the MED plug displacing upward and then outboard at a position where the plug stop pins had not completely cleared the frame stop pads. Additional damage marks showed that the left MED plug continued to displace upward and then aft as it moved outboard.

The upper guide rollers were intact on the frame, but the upper guide fittings on the left MED plug were fractured vertically through the inboard wall of each guide track. Examination revealed features consistent with overstress fracture with no evidence of preexisting cracks or damage. The fractured guide fittings exhibited arc-shaped deformation and were deformed inward and upward, consistent with guide rollers contacting and punching through the walls at the inboard side of each guide track. This contact deformation was consistent with the plug moving outboard before the plug had moved upward sufficiently to allow the upper guide fittings to clear the rollers.

Fracture patterns on the lower hinge guide fitting attachment bolts and flanges had overstress features indicative of a twisting load having been imparted on the lower hinge guide fittings. Evidence of such a twisting load is consistent with constraint from the lower hinge fittings as the left MED plug displaced outboard.

The examination also identified multiple, parallel dark lines of dust, dirt, and petroleum jelly that had accumulated near the seal contact area on the upper inboard side.[81] These lines were evidence that the left MED plug had moved incrementally upward during previous flight cycles. Postaccident testing using the airplane's right MED plug as an exemplar determined that upward movement of the right MED plug (after removing the vertical movement arrestor bolts and upper guide track bolts) required a static force estimated to exceed 150 lbs to push the door upward. Although a similar static force may have been required to displace the left MED plug, a dynamic loads analysis (which applied a modeling technique to vertical acceleration data from the accident airplane's QAR data) determined that inertial loads on the left MED plug during normal operations could substantially reduce the effective plug weight. Thus, it is likely that dynamic loads imparted by the vibrations and flexing associated with normal flight operations led to the gradual and incremental upward movement of the left MED plug.

Therefore, the NTSB concludes that the left MED plug displaced incrementally upward during previous flights; then, during the accident flight, it displaced upward to the point of stop pin to stop pad instability, then upward, outboard, and aft as it separated from the fuselage.

2.2.2.2 Absence of Damage on the Four Bolt Holes

The upper guide track bolt holes in both upper guide fittings were intact, and no evidence of deformation or paint disturbance from an upper guide track bolt, washer, or nut was observed in the hole bores or on the surfaces surrounding the holes on the inboard or outboard sides of the guide track. Similarly, the vertical movement arrestor bolt hole through the forward lower hinge fitting was not deformed and showed no evidence of damage from contact with a vertical movement arrestor bolt.

At the outboard side of the aft lower hinge fitting, the vertical movement arrestor bolt hole was elongated with cracks extending from the forward and aft sides of the hole. However, the hole elongation and cracking were associated with bending deformation of the hinge fitting shaft that occurred as the lower end of the left MED plug displaced outboard. No evidence of damage from contact with a vertical movement arrestor bolt was observed on the hinge fitting shaft, and no evidence of contact damage, deformation, or disturbance to the primer was observed on the

---

[81] Spirit AeroSystems used petroleum jelly to lubricate the MED plug seals during installation. Although this was not in conformance with Boeing specifications, it was unrelated to the left MED plug's separation. Spirit initiated corrective actions postaccident to use the specified lubricant.

recovered aft lower hinge guide fitting in the vertical movement arrestor bolt hole bore or the areas surrounding the hole.

Thus, the NTSB concludes that the absence of bolt contact damage or deformation around the holes associated with the vertical movement arrestor bolts and upper guide track bolts indicates that the four bolts that should have been installed to prevent the left MED plug's upward movement were missing before the plug moved upward off the stop pads.

Faint outlines associated with the upper guide track bolt washers were observed around the upper guide track bolt holes, indicating that hardware was installed at one time. This evidence is consistent with an NTSB review of manufacturing records and photographs indicating that the accident airplane's left MED plug had been installed but subsequently opened (requiring removal of the bolts) to facilitate additional work during the manufacturing process (see next section). Thus, the NTSB concludes that the left MED plug's vertical movement arrestor bolts, upper guide track bolts, and associated hardware were installed before the fuselage was delivered to Boeing but subsequently removed during the manufacturing process when the plug was opened to facilitate additional work.

2.3 Manufacturing History Related to Missing Bolts

2.3.1 Opening of Left Mid Exit Door Plug without Required Removal Record

Manufacturing records for the accident airplane showed that the left MED plug and fuselage frame were manufactured in accordance with applicable engineering drawings and that the left MED plug was installed (with the upper guide track bolts and vertical movement arrestor bolts in place) before the fuselage arrived at Boeing's 737 production facility in Renton.

While the fuselage was at the Boeing facility in Renton, Boeing personnel identified workmanship discrepancies with five rivets in the edge frame forward of the left MED plug. The rivets had been installed by a Spirit AeroSystems supplier, so Spirit personnel at the Renton facility were responsible for correcting the discrepancy. However, to allow access for the removal and replacement of the discrepant rivets, Boeing personnel needed to open the left MED plug. Such a disturbance of an accepted installation was a nonroutine task in the build process and required removing the four bolts (and associated castle nuts, cotter pins, and washers) that secured the plug.

Per the guidance specified in Boeing BPI "Perform Part or Assembly Removal," opening the MED plug met the criteria for the initiation of a removal record. Removal records provided a means to track the disturbance of previously accepted parts, assemblies, or installations and provided documentation to ensure that any disturbance to the configuration is subsequently restored. For example, correctly generated removal records listed the steps that needed to be performed to restore the disturbed installation back to an accepted condition and specified any signoffs from manufacturing personnel, quality assurance inspectors, or both associated with each step, as well as the final quality assurance signoff.

Manufacturing communications records showed multiple notations concerning the request for access to the discrepant rivet area between September 1, 2023, when Boeing personnel first documented the rivet issue, and September 17, 2023. During that time, SAT entries documented that the request was elevated twice to increase management visibility of the issue, and a September 17, 2023, SAT entry at 1815 showed that a senior manager discussed access with the door manager, noting that, "if removal needed, a removal needs to [be] written first."

According to the senior manager, once she learned that the fuselage was equipped with an MED plug, she determined that no door team member with the skillset needed to generate a removal record and open the MED plug was available and that the work would have to wait. The only door team member with the experience to open the left MED plug was on leave on September 18 and 19, 2023.

A September 18, 2023, SAT entry at 0700 indicated that the Boeing door manager stated, "door is being opened by mechanic." The timing of when the left MED plug was first opened is unknown, but the investigation found evidence that it was open as early as 1035 on September 18, 2023, and that there was no evidence that a removal record was generated.

According to Boeing barge logs for the accident airplane's fuselage, the door manager, a door master lead, and three door team members had shielded in (that is, used their employee badges to log their access to the work area) at the fuselage the morning that the left MED plug was opened; the door manager provided a postaccident statement, and the door master lead and the three door team members participated in interviews. None of the manufacturing personnel who provided a statement or participated in an interview indicated any knowledge of why no removal record was generated or who opened the left MED plug. The door manager who was on duty the day that the left MED plug was opened provided a statement indicating that he did not have an independent memory of asking that the left MED plug be opened, did not recall whether he saw the left MED plug opened at any time, and did not know why no removal record was generated.

Thus, the NTSB concludes that neither the door team manager nor any of the door team personnel on duty when the left MED plug was opened had any experience with opening an MED plug, and none said they had any knowledge of who opened it.

The NTSB further concludes that, whoever opened the left MED plug did not generate a removal record, which increased the risk that the closure would not be performed properly due to the absence of the documented steps for the bolts and hardware to be reinstalled and for a quality assurance inspection to verify that the installation was restored to accepted condition.

Per Boeing process, only door team members were allowed to perform work involving an MED plug and typically, but not always, the person performing the work generated the removal record. The lack of available information on who opened the left MED plug without the required removal record precluded us from determining whether the personnel involved had sufficient training and knowledge to fully understand the critical importance of generating the removal record before the task was performed. However, the investigation identified aspects of Boeing's production processes and training (discussed in the following sections) that increased the likelihood that Boeing manufacturing personnel could make this type of error.

2.3.1.1 Complexity of Business Process Instruction "Perform Part or Assembly Removal"

In a manufacturing environment, written guidance such as checklists or manufacturing build documents are crucial to ensuring workers have the information needed to complete tasks and help circumvent inherent limitations of human memory recall and inexperience, particularly when dealing with complex tasks or procedures (SKYbrary n.d., "Dirty Dozen"). For guidance to be effective, it must be clear, concise and unambiguous (Wright 1981, 131–41).

At the time that the accident airplane was in production, BPI "Perform Part or Assembly Removal," which provided guidance for determining the need for removal records when performing the nonstandard task of disturbing a completed installation, was more than 50 pages long, contained several hyperlinks to various other instructions, and provided more exceptions about when a removal record was not needed than direction indicating when it was. Even Boeing executives provided information indicating that the BPI was unwieldy and complex to use.

Human nature is such that, if a task or tool is proven cumbersome, a person is more likely to gravitate toward the option requiring the least amount of effort (APA 2018). Thus, manufacturing personnel who encounter difficulties working through all the complexities of the BPI guidance may be more likely to erroneously conclude that a removal record is not needed for a given task. Boeing had a history of compliance issues associated with failure to properly generate removal records, indicating evidence of confusion and lack of understanding among its workforce (see section 2.4.2). Therefore, the NTSB concludes that Boeing's BPI "Perform Part or Assembly Removal" lacked clarity, conciseness, and ease of use necessary to be an effective tool for manufacturing personnel to consistently and correctly determine when and how to generate a removal record.

As stated in section 1.12.2.3, in June 2024, Boeing completed another revision to the BPI, released additional training to emphasize when and why removal documentation was required, and implemented a change in CMES to allow only those personnel who had completed the additional training to initiate a removal record. We believe that effective guidance and recurrent training are critical to ensure that manufacturing personnel are proficient with its use when the need arises.

Therefore, the NTSB recommends that Boeing apply its updated SRM process to current and future revisions to BPI "Perform Part or Assembly Removal" to ensure that it provides clear and concise guidance for determining when a removal record is needed.

Further, the NTSB recommends that Boeing develop recurrent training on BPI "Perform Part or Assembly Removal" for Boeing manufacturing personnel that emphasizes the importance of removal records for product safety, prepares personnel to consistently and correctly determine when a removal record is needed, and ensures that a removal record is generated when required.

2.3.1.2 On-the-Job Training with Limited Exposure to Nonroutine Tasks

Newly hired Boeing 737 production line employees received initial foundational training that required proficiency checks before they would be released to the line. However, job-specific training, such as that required for Boeing 737 door team personnel, was typically provided on the job. For example, interviews with five door team personnel (one with about 25 years' experience with Boeing 737 doors and four with less than 2 years' experience with Boeing 737 doors) revealed that their job series relied heavily on on-the-job training, which was focused on performing routine tasks required for every build and relied on the expertise of more experienced personnel to train the less experienced workers.

Training for nonroutine tasks, such as generating a removal record and opening an MED plug, would occur as a matter of opportunity rather than as part of a structured program. However, because the need to open an MED plug did not arise often, few such opportunities existed, particularly for the newly hired door team members. For example, from 2022 to September 2023 (before the accident airplane was in production), removal records related to opening or fully removing an MED plug were identified for 6 Boeing 737 airplanes in the Renton facility, which, at the time, produced a minimum of about 30 airplanes per month.

As stated previously, on the day the left MED plug was opened, the most experienced door crew member who was typically tasked with opening an MED plug, should the need arise, was on leave and unavailable to assist. Neither the door team manager nor the four other door team personnel who were on duty that morning (one of whom was a door master team lead) had ever opened an MED plug.

As a training methodology, on-the-job training is often used because it provides workers with the opportunity to learn hands-on and develop competencies and skills required for a job while in the actual working environment. It can also be cost effective for an organization, as the workers learn the skills they need to do the job while simultaneously contributing to production (Barron et al. 1997). Aircraft systems are complex; therefore, it is nearly impossible to perform many tasks without substantial technical training, current relevant experience, and adequate reference documents.

On-the-job training can be an effective way to provide a higher fidelity learning experience, particularly if it supplements a robust foundational training program. However, on-the-job training also has several disadvantages. A significant disadvantage is that training content is subject to the capabilities of the trainer, such that each trainee may have a different experience depending on who trains them (Vasanthi and Basariya 2019, 671–7). Another disadvantage is an increased risk to production quality due to the introduction of undesirable norms from the trainer to the trainee working directly on the product.[82] Further, compared to formal off-job training programs, on-the-job training progress is not as easy to scale, to ensure performance metrics are being met, or to document (Wood 2004).

For on-the-job training to be successful, the program must be structured so that trainers and trainees have a clear understanding of all the tasks that are required for a technician to be considered fully qualified, scalable so that trainers and trainees can use a grading structure to track progression, and capable of documenting the results.

However, Boeing required no task list, grading structure, or training documentation for the on-the-job training performed by door team members. As a result, there was no record of which door team personnel had any experience with or exposure to generating the removal record and performing the tasks required for opening and closing an MED plug. Such training documentation would be useful to help Boeing better identify training needs, reduce subjectivity in the training provided, and maximize training experiences, such as exposure to nonroutine tasks, when the opportunities arise.

[82] Norms refer to workplace practices – good and bad – that develop as part of a workplace culture.

The NTSB concludes that Boeing's on-the-job training was unstructured, undocumented, and focused primarily on routine build tasks, which decreased the likelihood that door team personnel with limited exposure to nonroutine tasks would be able to correctly perform the process for opening an MED plug, including generating the required removal record.

Therefore, the NTSB recommends that Boeing develop a structured on-the-job training program that identifies and defines tasks necessary for manufacturing personnel to be considered fully qualified in their job series and includes a grading system for trainers and trainees to track progress and determine competence. The NTSB also recommends that Boeing document and archive the results of training provided and received as part of the program recommended in Safety Recommendation A-25-30 to support future data analysis.

2.3.2 Incomplete Closure of Left Mid Exit Door Plug

The investigation determined that, once the rivet work was completed on the accident airplane, the left MED plug was closed sometime during the second shift on September 19, 2023. Only door team personnel were allowed to close an MED plug, but none were on duty at the time the plug was closed. None of the manufacturing personnel who provided a statement or participated in an interview indicated knowledge of who performed the final closure of the plug. Further, none of the second shift manufacturing personnel on duty at the time would have been knowledgeable about how to close and secure the plug because it was outside their job series responsibilities.

Also, manufacturing records show that IP "OK to Install Blankets" was completed for the accident airplane on September 20, 2023, which allowed for the installation of the insulation blankets that covered the interior of the left MED plug, obscuring from view the area where the bolts were missing. Without a removal record, which should have been attached to the NCR and NCO that documented the need for rivet rework identified by this IP, there was no indication of the steps needed to properly close the plug and that quality assurance signoffs were needed to verify that the left MED plug installation had been restored back to an accepted status. As a result, with no removal record to indicate that the left MED plug installation had been disturbed, the quality assurance inspector who performed the final quality assurance signoff for IP "OK to Install Blankets" verified only that the signoffs were completed for the documented workmanship issues, such as the discrepant rivets.

Thus, the NTSB concludes that only door team personnel were allowed to perform work on doors and MED plugs, but none were on duty at the time the left MED plug was closed. The NTSB further concludes that due to the absence of a removal record indicating that the left MED plug installation had been disturbed, no quality assurance inspection of the plug closure was performed.

After the accident, Boeing worked with Spirit AeroSystems to develop a design enhancement intended to ensure the safety of MED plug installations. The design enhancement would add two secondary retention devices to prevent an MED plug from moving upward if the vertical movement arrestor bolts and upper guide track bolts were not installed, prevent the sidewall panels from being installed unless the devices were engaged, and add lanyards to the vertical movement arrestor bolts and upper guide track bolts so that they remain hanging on the frame or plug when removed, providing a visual indication when the bolts were not installed.

As of May 2025, Boeing and Spirit were continuing certification planning and compliance work, which will require notifying the FAA. Boeing stated that, once the design enhancement is certified, installation in all applicable new production airplanes would likely begin sometime in 2026, and that it would release a service bulletin to address retrofits for in-service airplanes.

The NTSB concludes that the postaccident design enhancement of the MED plug, if certified by the FAA and implemented by Boeing, will help ensure the complete closure of an MED plug following opening or removal. Therefore, the NTSB recommends that Boeing continue the certification process for the design enhancement for MED plugs to ensure that, once the design enhancement is certified, all applicable newly manufactured airplanes are equipped with the enhancement. The NTSB also recommends that Boeing, once the design enhancement for MED plugs is certified, issue a service bulletin to address retrofitting in-service MED plug-equipped airplanes with the design enhancement. The NTSB further recommends that the FAA, once it completes the certification of Boeing's design enhancement for ensuring the complete closure of Boeing 737 MED plugs following opening or removal, issue an airworthiness directive to require that all in-service MED plug-equipped airplanes be retrofitted with the design enhancement.

2.4 Quality Assurance Processes and Oversight Deficiencies

For Boeing's 737 production line to maintain a high level of quality control, Boeing needed to have adequate resources in place. Resources can include trained personnel and information required for those personnel to understand and perform tasks. However, as described in the previous sections, Boeing lacked the comprehensive training and clear guidance needed to ensure that its Boeing 737 door team personnel and others could consistently meet quality and safety standards related to performing parts removals (including generating a removal record) and quality assurance that could identify quality escapes resulting from human error.

2.4.1 Workforce Experience Change Management

In 2022, Boeing sought to increase production to pre-2018 levels and increased hiring to compensate for the employees lost over the previous 4 years.[83] Boeing hired people onto the Boeing 737 production line who did not have previous manufacturing experience. Research has shown that lack of experience can lead workers into misjudging situations and making unsafe decisions (SKYbrary n.d., "Dirty Dozen").

However, if the infrastructure is in place to facilitate comprehensive training, including clear guidance and effective oversight, a relatively inexperienced workforce can still meet quality and safety standards. To determine how change in workforce manufacturing experience levels may have affected Boeing production, a comprehensive change management assessment, including a risk assessment, would have been needed.

One aspect of change management relevant to manufacturing is "the process of continually renewing an organization's direction, structure, and capabilities to serve the ever-changing needs of external and internal customers" (Moran and Brightman 2001, 111–9). It is needed to forecast the impact that change will have on an organization and to ensure the transition is smooth and has the desired effect (R. By 2005, 369–80). The risk assessment portion of change management is designed to identify any potential hazards associated with the change, assess the risks associated with the hazard, and help develop controls to mitigate the risks. Components of change management include providing training and support throughout the change process; using effective communication and feedback tools to ensure messaging is desirable and consistent; and using metrics to measure performance before, during, and after the change (Miller 2020).

Before the accident, Boeing used a host of metrics designed to provide information about production effectiveness, including an assessment on whether to increase production. Although identifying and tracking performance indicators is a crucial part of quality assurance, this approach tends to be inherently reactive. For example, according to Boeing executives interviewed, a performance indicator's threshold had to be exceeded to trigger an event for further analysis.

Under change management, the impacts of a change are considered proactively, thus, providing an opportunity for an organization to address potential issues before they can result in negative safety outcomes. Workforce manufacturing

[83] In 2018 and 2019, following two fatal accidents involving Boeing 737 MAX airplanes, the FAA grounded the aircraft and halted deliveries for several years. Boeing significantly decreased its production of the airplane, resulting in workforce reductions, which were exacerbated by the global pandemic in 2020.

experience and how it might affect quality control is the type of change that should have been assessed through change management.

Thus, the NTSB concludes that, because Boeing did not conduct a change management assessment to identify and address the risks associated with using a workforce with reduced experience, including hiring many with little or no previous manufacturing experience, it missed an opportunity to proactively implement mitigations to ensure quality standards were maintained.

2.4.2 Persistence of Issues with Business Process Instruction "Remove Part or Assembly"

As stated previously, at the time that the accident airplane was in production, BPI "Perform Part or Assembly Removal," which contained the guidance for determining the need to generate a removal record associated with disturbing a previously accepted installation (like an MED plug), was complex and difficult to use. Boeing was aware of issues with the BPI, having substantively revised it 11 times from 2013 to 2023, based on findings of activities such as scheduled periodic reviews, internal reporting and audits, and FAA surveillance.

The BPI was also referenced in 16 regulatory compliance issues from 2018 to 2023, consisting of 9 voluntary disclosures that Boeing submitted to the FAA and 7 compliance actions that the FAA submitted to Boeing. Regulatory issues included but were not limited to workers failing to generate a removal record when it was required.

2.4.2.1 Boeing's Ineffective Corrective Actions

Boeing had a Regulatory and Quality System Oversight team to work with the FAA to investigate compliance issues, develop resolutions, and prescribe corrective actions, which the FAA could accept or reject.

Problems with BPI "Perform Part or Assembly Removal" were identified in numerous Boeing internal audits across production lines and employee Speak Up reports, and Boeing's corrective actions since 2013 have included revisions, quality alerts, workshops, and training sessions dedicated to ensuring its use. Each corrective action was accepted by the FAA and implemented by Boeing, yet problems with the process, including unauthorized removals that lacked the required documentation, persisted until this accident occurred. (As stated in section 2.3.1.1, the BPI lacked clarity, conciseness, and ease of use necessary to be an effective tool for workers in the manufacturing. Adherence to the BPI would have resulted in a removal record for the accident airplane's left MED plug.)

Research has shown that, for every serious accident, there were likely multiple minor incidents and even more near misses as precursors to the accident (Heinrich 1930, 83–92). Because of the relative difficulty in detecting removal process noncompliance (for example, the lack of a removal record for the accident airplane was not detected until the MED plug installation became the subject of an accident investigation), its potential effect can remain latent, thereby, making it even more insidious. Since numerous noncompliance occurrences were detected, the BPI's revision history and the feedback from the production lines indicated that there were precursors to the accident.

Thus, the NTSB concludes that, although accepted by the FAA, Boeing's corrective actions were ineffective to address the persistent deficiencies with Boeing's BPI "Perform Part or Assembly Removal," which had a documented history of compliance issues for at least 10 years before the accident.

As part of the process to develop corrective actions for the BPI, Boeing would have conducted an SRM. As stated previously, the company routinely applied a modified risk assessment to its rate readiness review process but was new to applying SRM to hazard and risk identification under the SMS construct. The modified risk assessment considered issues that had a direct effect on Boeing's ability to produce aircraft (such as the rate of supply and available manpower to work the line). In contrast, however, a fully developed SRM would consider hazards and conditions that could manifest into negative safety outcomes that might lead to significant incidents or accidents.

Although Boeing's rate readiness review was a proactive effort necessitated by a desire for change, the SRM activities Boeing initiated related to the BPI and training were in response to events rather than proactively determined based on KPI trends. Further, the persistence of ineffective corrective actions in the years before the accident suggests that Boeing's SRM process is inadequate (see section 2.5 for more information).

In addition, the investigation of this accident identified manufacturing process discrepancies related to Boeing's documentation of IP "OK to Install Blankets," which was a traveled work item for the accident airplane (due to the NCR and NCO for the rivet rework), and IP "Installation of Insulation Blankets," which was completed out of sequence before IP "OK to Install Blankets" was completed. Given the multiple process discrepancies that were discovered during this investigation's review of the few IPs that pertained specifically to the area of the left MED plug, the NTSB is concerned that these discrepancies suggest additional systemic compliance issues with Boeing's manufacturing processes.

For a complex manufacturing process such as Boeing's, where thousands of components are being integrated into a final assembly, it is realistic to expect that predefined plans may need to be adjusted at times to accommodate for manufacturing nonconformances. However, improperly managed traveled work can increase risk and interfere with the ability to complete other planned work, resulting in cascading delays in production.

The NTSB notes that, although the NCR and NCO for the rivet rework was correctly linked to IP "OK to Install Blankets," the short stamp should have been applied at each step in the IP to identify the need to reaccomplish those steps for the disturbed areas of the left MED plug after the rivet rework was completed. Although none of those steps in the IP specifically addressed verifying the installation of the left MED plug's vertical movement arrestor bolts and upper guide track bolts, a visual reinspection of the area for workmanship discrepancies, including open holes, would have been performed.

Thus, the NTSB concludes that, although Boeing's short stamp process for deferred or traveled work does not negate the need to generate a required removal record for disturbed installations, had the short stamp process been correctly applied on IP "OK to Install Blankets" for the accident airplane, it may have provided an opportunity for personnel to detect the left MED plug's missing bolts and attachment hardware.

Therefore, the NTSB recommends that Boeing revise its SRM process to ensure that it 1) identifies the root causes of manufacturing process compliance issues, like the persistent deficiencies with BPI "Perform Part or Assembly Removal" and other production process inconsistencies identified in this investigation, and 2) evaluates the effectiveness of corrective actions.

2.4.2.2 Ineffective Federal Aviation Administration Oversight

The FAA's role in providing the oversight of Boeing's production lines, through its compliance and enforcement actions and annual audit activities, is crucial to ensuring that Boeing and its employees are adhering to the standards set forth by policy and regulation.

The FAA inspectors assigned to Boeing said that, before the accident, their surveillance findings typically consisted of tool and foreign object control violations, routine deviation from work instructions, and training deficiencies. An example of a common training deficiency was a worker not knowing how to find the manufacturing documents needed for a specific job. These categories typically generated the most corrective actions and compliance issues (and were likely also indicative of an inexperienced workforce as discussed in section 2.4.1). FAA inspectors recorded their audit and surveillance findings in ACAIS.

The FAA certificate management program relied on the RBRT and ACAIS to determine what risks were prevalent in the Boeing production system and to develop a certificate management plan, which prescribed their audit activities for each year. However, based on the information provided by the inspectors interviewed, it was unclear how (if at all) the RBRT incorporated the results of any past audits and noncompliance findings when developing its risk assessment that served as the basis for determining what relevant audits were required for the next year.

From October 2022 to September 2023, FAA inspectors documented 68 alleged noncompliances identified during audit activities at Boeing's Renton facility; however, none referenced BPI "Perform Part or Assembly Removal." This lack of specific, trackable references to the BPI in the audit activities is concerning because, as stated in the previous section, issues with the BPI have been ongoing since 2013 and reflected in FAA enforcement records since 2018. (FAA enforcement records were typically retained for only 5 years.) For example, since 2018, issues with the BPI were reflected in 16 regulatory compliance actions, which FAA inspectors and Boeing's Regulatory and Quality System Oversight organization worked together to address; thus, the FAA was aware of these issues.

The lack of documented audit findings specific to BPI "Perform Part or Assembly Removal," suggests that the RBRT and ACAIS lack the functionality to effectively account for historic, systemic compliance issues with a specific manufacturing process when determining each year's certificate management plan for Boeing and its suppliers.

Thus, the NTSB concludes that the FAA's compliance and enforcement surveillance, audit planning assessments, and records systems were deficient and lacked the functionality necessary to identify repetitive and systemic discrepancies and nonconformance issues with Boeing's BPI "Perform Part or Assembly Removal," including previous instances of undocumented part removals.

On October 9, 2024, the Department of Transportation (DOT), Office of Inspector General (OIG) issued the results of its 2-year audit on the FAA's oversight of Boeing's production of the Boeing 737 and 787 airplanes due to "multiple manufacturing issues" since 2018.[84] The DOT OIG's audit activities, which began about 6 months before this accident, included a review of "multiple independent

[84] The audit was requested on November 18, 2021, by Chair Peter DeFazio and Ranking Member Sam Graves of the House Committee on Transportation and Infrastructure and Chair Rick Larsen and Ranking Member Garrett Graves of the Subcommittee on Aviation. On May 23, 2022, Chair Maria Cantwell of the Senate Committee on Commerce, Science, and Transportation also requested the audit (DOT OIG 2024, 2). The DOT OIG initiated its audit activities in July 2022 and concluded them in August 2024 (DOT OIG 2024, 32).

reports on Boeing's production issues, including an NTSB report and joint FAA-industry reviews from 2014 and 2024" (DOT OIG, 2024, 32).

The conclusion of the DOT OIG's audit activities coincided with the August 2024 release of the NTSB's public docket for this accident, which included our July 3, 2024, Manufacturing Records and Human Performance Factual Report that summarized the factual information we compiled about the FAA's oversight of Boeing during our safety investigation of the circumstances of this accident.[85] In its report, the DOT OIG identified deficiencies similar to those we identified with the FAA's ability to plan and manage effective audits and identify potential repetitive issues in Boeing's production processes.

The DOT OIG also recommended that the FAA take actions to address these issues, and the DOT OIG report included a copy of the FAA's September 26, 2024, initial response (DOT OIG 2024, 29–30 and 37–38). In its response, the FAA stated that it initiated actions to enhance its oversight of Boeing (the FAA had previously provided us with similar information, as reflected in section 1.12.1.3 of this report), and it provided target implementation dates for various responsive actions ranging from September 30, 2025, to March 31, 2028 (DOT OIG 2024, 38).[86]

The NTSB is encouraged by the FAA's initial progress on issues identified as part of our safety investigation and in response to issues identified by the DOT OIG. To ensure that the FAA's completed actions adequately address the issues we identified in this investigation, the NTSB recommends that the FAA revise its compliance enforcement surveillance system to ensure that it provides the necessary functionality for FAA managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes.

The NTSB also recommends that the FAA revise its audit planning activities to ensure that they provide the necessary functionality for FAA managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes.

The NTSB also recommends that the FAA revise its records systems to ensure that they provide the necessary records for FAA managers and inspectors overseeing

[85] The factual information we compiled in our public docket for this investigation, including the transcripts from our August 2024 public hearing, wholly supported our development of the analysis of the FAA oversight issues discussed in this report.

[86] One action with an earlier target date was related to a DOT OIG-identified issue that was beyond the scope of our investigation of this accident.

production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes.

The NTSB also recommends that the FAA, once the actions in Safety Recommendations A-25-16 through -18 are completed, develop guidance for FAA managers and inspectors who provide oversight of production approval holders on how to identify, record, track, and effectively address repetitive and systemic discrepancies and nonconformance issues, to include strategies for assessing the effectiveness of corrective actions taken by the production approval holder during the previous year when developing the next year's certificate management plan.

The NTSB also recommends that the FAA, once the actions in Safety Recommendation A-25-19 are completed, provide FAA managers and inspectors who provide oversight of production approval holders with recurrent training on how to identify, record, track, and effectively address repetitive and systemic discrepancies and nonconformance issues, to include strategies for assessing the effectiveness of corrective actions taken by the production approval holder during the previous year when developing the next year's certificate management plan.

Further, the NTSB recommends that the FAA retain historical compliance enforcement surveillance and audit records older than 5 years and provide FAA managers and inspectors access to these records to enhance their oversight planning for production approval holders.

2.4.3 Need for Improved Quality Escape Mitigation Strategy

Boeing had a QMS, which was a structured system of processes, procedures, records, and resources intended to ensure that each product met its approved design and was safe to operate. Boeing's QMS was externally audited by the FAA in accordance with FAA Order 8120.23A and internally audited per Boeing's quality manual. Boeing's QMS covered several elements of the production process, including quality escapes. A quality escape is a product that does not conform to its approved design but is released from Boeing's quality system.

Boeing's quality manual described how to identify, control, document, and disposition a nonconforming product but did not specifically address escapes that result from human error. The guidance for quality escapes was based primarily on the assumption that there is a physical component to work with to begin disposition.

However, this accident did not result from a damaged or unusable part but rather the absence of a component initiated by a human error lapse.[87] Human error models help identify accident causation by showing how multiple system failures can align, grounded in the theory that, within a robust system, the introduction of a single error is almost never the only cause of an accident. Rather, several barriers of defense must fail for the error to lead to an accident (Reason 1990).

For this accident to have occurred, several barriers to quality escapes were breached. As discussed in previous sections,

- workforce turnover in recent years resulted in a lesser experienced workforce;
- the most knowledgeable door crew member was unavailable to assist on the day the left MED plug was opened, and no door team personnel were working during the shift when the left MED plug was closed;
- the BPI guidance for determining when a removal record was needed was too complex and unwieldy to be used as an effective tool for workers;
- on-the-job, unstructured training for door team personnel did not ensure that all personnel had training exposure to nonroutine tasks, like opening an MED plug and generating a removal record;
- the required removal record documenting the opening of the left MED plug was not created; and
- any quality assurance inspections that could have detected the left MED plug's missing hardware did not occur due to the lack of the removal record.

In addition to what Boeing's QMS prescribed for the identification and disposition of damaged or unusable parts, the quality assurance manual should specifically address how to identify escapes that are the direct result of human error because, as demonstrated in this accident, human errors can go undetected and result in near-catastrophic events. The manual should establish an assessment process to identify the factors that contributed to the human error and the safety and quality control barriers that failed and allowed the effects of error to progress.

Thus, the NTSB concludes that Boeing's quality escape guidance, which focused on components rather than the actions of people performing tasks, did not adequately address controls for human error, leaving a gap in Boeing's ability to identify and build effective escape mitigation strategies.

[87] A human error lapse is an unintended action that occurs when a person forgets to carry out a step in a procedure or deviates from an intended plan (Reason 1990).

Therefore, the NTSB recommends that Boeing, as it integrates its QMS and SMS, develop a process that can identify quality escapes that result from human error, assess them using a system specifically designed to identify factors that contribute to such errors, and implement effective mitigation strategies.

2.5 Need for Continued Development of Safety Management System

At the time of the accident airplane's production, there was no regulatory requirement for a Part 21 SMS, but, in accordance with a 2015 settlement agreement between the FAA and Boeing, Boeing had implemented a VSMS that became operational in June 2021. Boeing's VSMS structure contained the same four pillars as a regulatory SMS; however, each exhibited varying degrees of implementation and success. At the time of the accident, Boeing was actively working to integrate SMS principles into its QMS while awaiting the final rule for Part 5 for production approval holders, which would provide additional guidance about how to meet regulatory standards for the program.[88]

The FAA SMS program advisor who assisted Boeing in developing its VSMS said that that Boeing had performed well in developing and implementing it and that the FAA accepted it because it established the processes and procedures necessary for an SMS. Because the program was non-regulatory, FAA surveillance of the Boeing's VSMS, including its integration with QMS processes, had not yet begun. The FAA inspectors interviewed had not yet attended SMS training, and, therefore, were not knowledgeable about what an SMS entailed or what their requirements would be for oversight.

According to information that Boeing provided during the NTSB's August 2024 investigative hearing for this accident, Boeing's QMS was a compliance and conformance system focused on the quality of its products and services, whereas its SMS was a continued operational safety system focused on the safety performance of its design, build, and support processes. An FAA witness at the hearing stated that the FAA's expectation was that the QMS would provide triggers to the SMS, such that any issue identified by the QMS should trigger the SMS that an SRM exercise was needed.

As stated in the previous section, the NTSB's investigation identified issues with Boeing's on-the-job training and its BPI for removals and discovered that Boeing

[88] The final rule for 14 *CFR* Part 5, effective May 28, 2024, extended the requirement for an SMS to all certificate holders operating under the rules for commuter and on-demand operations, commercial air tour operators, production certificate holders that are holders or licensees of a type certificate for the same product, and holders of a type certificate that license out that type certificate for production.

senior leadership had previous awareness of these issues. At the time the accident airplane was in production, an SRM activity dedicated to training and Speak Up reports and an SRM activity dedicated to the BPI were still in progress. Therefore, the final determination of the SRM activities and the resultant mitigation strategies were not developed and in place in time to prevent the accident airplane from leaving the factory with the left MED plug improperly installed.

Thus, the NTSB concludes that, in the 2 years before the accident airplane's production, Boeing's VSMS was an immature program that lacked formal FAA oversight and did not proactively identify the risk of the quality escape that occurred.

As stated previously, at the time of the accident, Boeing was new to applying SRM to hazard and risk identification under the SMS construct. Before the accident, Boeing used KPIs as part of a larger body of metrics Boeing repeatedly monitored under its QMS to measure production health for the Boeing 737 production line. Quality control metrics such as nonconformances, supplier conformance, how long an aircraft took to progress through the build, escapements, and regulatory compliance were routinely assessed at multiple tiers of leadership.

After the accident, the FAA mandated that Boeing produce a comprehensive plan as to how it was going to address its quality control and safety issues. Boeing selected the following six KPIs it felt would be best representative of its quality and safety health:

- employee proficiency
- notice of escapes
- supplier shortages
- rework hours per airplane
- travelers at factory rollout, and
- ticketing performance.

According to Boeing's senior vice president of quality, these KPIs were refined in collaboration with the FAA. Under this refinement effort, these KPIs, which were already part of a larger body of metrics Boeing repeatedly monitored under its QMS, became more risk-focused rather than production-focused. Each of the six KPIs was composed of defined criteria that helped identify areas of potential risk and triggered corrective action through its SMS, and each had helped Boeing conduct more targeted safety risk assessments in priority areas and maintain production health.

The NTSB believes that the new SMS requirement and FAA oversight associated with a regulatory SMS will help ensure that Boeing will focus its efforts on fully developing its program, including the continued development of more effective

SRM activities and other proactive mitigations. As stated previously, on October 9, 2024, the DOT OIG issued the results of its 2-year audit on the FAA's oversight of Boeing's production. The DOT OIG report identified the need for formal FAA reviews of Boeing's SMS to ensure that it integrated the data it needs to "apply lessons learned from regulatory noncompliances" (DOT OIG 2024, 23). As a result, the DOT OIG recommended that the FAA establish procedures to periodically evaluate Boeing's SMS, including how it interfaces with Boeing's existing quality system (DOT OIG 2024, 30).

Therefore, the NTSB concludes that having a fully developed SMS, implemented at every level of the quality management and production process, will provide Boeing with a systematic approach to proactively identifying and managing the human risks associated with aircraft production.

In addition, for Boeing's SMS to be fully effective, everyone involved in achieving the company goals and demonstrating desired behaviors must be fully aware of company policies, processes, and procedures and be held accountable for adherence to them. Based on information obtained from interviews with Boeing 737 production line personnel, it was clear that knowledge about Boeing's VSMS or what constitutes a positive safety culture had not yet permeated to the production line personnel.

Of the personnel interviewed, none were able to describe what an SMS was or what Boeing's safety policy dictated. Most associated "safety culture" with maintaining occupational safety and health standards. As part of the safety promotion aspect of SMS, if safety policy is not communicated properly, or if buy-in isn't sought from all levels of production, employees are less likely to actively support the intended goals, thereby, adding additional risk to the system.

Although the personnel interviewed did not recognize SMS by name, some were able to describe aspects of safety promotion and positive safety culture as it related to anonymous feedback and reporting systems. Several said they felt comfortable voicing concerns to their managers and were familiar with the availability of Speak Up. Several said they were relatively confident that their concerns would be heard, and none stated they were ever pressured to do work that was outside their capabilities.

Conversely, some personnel expressed apprehension about giving input for fear that they might be identified as a troublemaker or targeted for reprisal. Being able to speak about positive and negative aspects of safety culture even without knowing the ideology behind it shows that on some level, Boeing employees were aware of what a positive safety culture should look like.

With regard to workplace pressure, several production line personnel mentioned that pressure existed, but most did not consider it undue, noting that the desire to meet a deadline was an inherent part of the day-to-day operation. However, these personnel interviewed represented a small sample size of a much larger workforce.

In February 2024, an expert panel formed under the 2020 Aircraft Certification, Safety, and Accountability Act (public law 116-260, division 5), Section 103, released its final report on its review of aspects of Boeing's safety management processes, including its SMS and safety culture.[89] Among its findings, the panel identified "a disconnect between Boeing's senior management and other members of the organization on safety culture. Interviewees…also questioned whether Boeing's safety reporting systems would function in a way that ensures open communication and non-retaliation." Although the expert panel's activities were focused on the personnel and activities within Boeing's organization designation authorization unit, those activities were conducted under the same SMS construct that applied to Boeing's production lines.

The NTSB notes that one of the most common reasons an employee might not speak up in the workplace is due to fear of reprisal, which is one of the concerns a just and positive safety culture is designed to prevent. Real or perceived employee punishment can negatively affect other employees by lowering morale, creating a climate of fear, hindering teamwork, reducing productivity, and causing a sense of uncertainty as they worry about becoming the next target of disciplinary action (Arvey and Ivancevich 1980, 123–32; Arvey and Jones 1985, 367–408; and Ball, Trevino, and Sims 1994, 299–322). For example, if someone did know more about the removal or reinstallation of the accident airplane's left MED plug, this kind of environment would not be conducive to that person being comfortable with sharing what they know during the investigative process.

To perform a safety culture assessment in the context of this investigation, the NTSB decided to initiate the development of a safety culture survey to be distributed to Boeing personnel, including those on the Boeing 737 production line. We completed the development of the survey in time for a planned launch date of October 1, 2024; however, about 2 weeks before our planned launch date, the International Association of Machinists & Aerospace Workers, district 751, elected to go on strike due to failed contract negotiations with Boeing leadership (IAW 2024).

As a result of this work-stoppage, we decided to postpone our planned survey until at least mid-January 2025 to mitigate the potential for bias. The postponement

[89] The panel was convened to review Boeing's organization designation authorization unit activities, which were performed as part of the Boeing Commercial Airplanes' business unit and under its SMS.

also considered the need to allow time for Boeing operations to stabilize following the strike, as well as the desire to maximize workforce participation by waiting until after the end-of-the-year holiday season.

However, the strike continued for 7 weeks, ending in early November 2024. During that time, Boeing's production was effectively halted. In December 2024, the NTSB assessed that the results of any survey conducted at this point would not give an accurate depiction of the safety culture that existed in September 2023, when the accident airplane was being manufactured and decided not to administer the survey.

Thus, the NTSB concludes that, due to the mixed perspectives provided by the relatively small sample size of employees interviewed about the accident airplane's left MED plug and the prolonged work stoppage at Boeing that precluded the NTSB from conducting a broader safety culture survey, an assessment of Boeing's safety culture, including whether any adverse pressure existed on the production line, could not be performed as part of this investigation.

The NTSB notes that, after the accident, in addition to working with the FAA to refine and focus its KPIs, Boeing hosted several safety and quality "stand downs" and smaller safety talk sessions with production line personnel to elicit feedback about the production process. The NTSB notes that such efforts are essential in establishing lines of communication with those closest to the work being performed. As mentioned previously, a healthy safety promotion program means open communication between the production line personnel, middle management, and senior executive levels of the organization. The stand downs and talk sessions offered the production line workers a chance to express their experiences and concerns in various forums. For example, through these sessions, Boeing leadership learned more about production line personnel's concerns about ineffective training and the parts removal process, which fed back into the company's SRM process.

Offering the opportunity to speak in a group setting in addition to reporting through the typical systems increases the likelihood Boeing would receive actionable feedback. People often feel more comfortable speaking in groups than alone because the attention is shared among everyone in the group and there is less individual focus. It can make for a less intimidating environment where everyone can contribute to the conversation (Indeed 2025).

Workers are also more likely to feel they are part of the solution and have buy-in if they recognize their concerns are being considered—a factor that is important in a healthy safety culture. To be truly effective, Boeing would have to balance the large groups sessions with smaller or even one-on-one sessions to ensure more dominant personalities aren't the only ones being heard, which can be a drawback with engaging only with large groups.

Although the NTSB was unable to methodically assess whether safety culture elements may have affected the production of the accident airplane's fuselage, we recognize that safety culture is an essential contributor to risk reduction. The NTSB believes that, for there to be continuous improvement at Boeing, production line personnel must recognize their shared responsibility in supporting a positive safety culture and identifying hazards and risks. Further, as part of a just culture, which encourages employees to report errors and safety concerns without fear of blame or reprisal, personnel must be empowered to "see it, say it."

Based on the idea that mistakes are subject to shared accountability and the result of faulty systems rather than assigning blame to the actions of individuals, a just culture focuses on learning from mistakes to improve the system (SKYbrary n.d., "Just Culture"). Achieving this level of understanding among Boeing manufacturing personnel will require training, continuous communication, and demonstrated senior level commitment to adhering to safety policies as Boeing continues to develop its SMS.

The NTSB believes that Boeing's ongoing activities with the team of FAA subject matter experts, which continuously reviews Boeing's progress and effectiveness in addressing audit findings and expert panel recommendations, provides an opportunity to perform ongoing assessments of Boeing's safety culture as Boeing continues to develop its SMS. For example, the expert panel that examined Boeing's SMS and the safety culture of its organization designation authorization unit could apply that methodology to the various production lines.

Thus, the NTSB concludes, that, for future implementation of Boeing's regulatory SMS and integration into its QMS to be successful, accurate and ongoing data about its safety culture is needed. Therefore, the NTSB recommends that the FAA convene an independent panel to conduct a comprehensive review of Boeing's safety culture. The findings should be used to enhance the ongoing development of Boeing's regulatory SMS and the integration of its SMS into its broader QMS.

2.6 Other Safety Issues

2.6.1 Need for Flight Crew Hands-On Emergency Oxygen Mask Training

As described in section 2.2.1.1, during the rapid depressurization emergency, the captain and the first officer appropriately donned their oxygen masks in accordance with procedures and worked to overcome the communications challenges associated with the loud noise on the flight deck.

However, when they subsequently removed their oxygen masks, they did not complete the procedures necessary to reestablish communications using their headset boom microphones. As a result, the noise coming through their headsets (from the oxygen mask microphones) made it impossible for them to hear each other or air traffic control, so they resumed using their oxygen masks for the remainder of the flight.

On the Boeing 737 MAX airplanes, when the oxygen mask is removed from the stowage box, the oxygen mask microphone is automatically selected (and the headset boom microphone deselected). To reactivate the headset boom microphone after removing the mask, the Boeing 737 MAX procedures require the crew to close the right stowage box door and push the TEST/RESET switch on the box for the system to deselect the oxygen mask microphone and reselect the headset boom microphone.

These procedures differ from those of the Boeing 737 NG airplanes, which are equipped with a manual MASK/MIC switch on the audio control panel and require the crew to manually select which microphone is in use. Both pilots had significantly more flight experience in NG airplanes, and, during the accident flight, the first officer initially reached for the switch to turn on the mask microphone before remembering that activation was automatic.

When the Boeing 737 MAX airplanes were first delivered to Alaska Airlines, the pilot group underwent differences training, which consisted of 3 hours of computer-based training modules and 2 hours of initial familiarization training in the simulator. Only one computer-based training slide addressed the differences between the Boeing 737 MAX and NG oxygen mask systems and communications procedures (which were also described in the Alaska Airlines 737 Systems Handbook).

No hands-on experience with donning the oxygen mask and performing the associated communications procedures was included in the flight simulator training; thus, neither of the accident flight's pilots had ever performed the procedures in a Boeing 737 MAX flight simulator. Further, the NTSB found that, before the accident, even the three Alaska Airlines simulator instructors who assisted with postaccident simulator scenarios were unaware of the need to push the TEST/RESET button to reactivate the headset boom microphone, a step necessary to reestablish headset communications on the Boeing 737 MAX. Thus, the NTSB concludes that, while hands-on oxygen mask simulator training was provided to the flight crew before the accident, it lacked realistic, scenario-based exercises and, therefore, failed to adequately prepare them for potential real-world events.

After the accident, Alaska Airlines updated company manuals and training materials to help ensure that flight crews understand the differences between the Boeing 737 NG and MAX oxygen systems, and the airline included hands-on training performing the procedures during continuous qualification and line-oriented flight training simulator events.

The NTSB has a longstanding interest in the importance of providing flight crews with the guidance and training they need to prepare them to quickly and effectively use their oxygen masks and maintain communications during emergencies that require their use. In 2000, we issued a safety recommendation to the FAA to require operators of all pressurized cabin aircraft to provide guidance to pilots on the importance of a thorough functional preflight of the oxygen system, including, but not limited to, verification of supply pressure, regulator operation, oxygen flow, mask fit, and communications using mask microphones.

The FAA agreed with the intent of the recommendation, updated guidance in Advisory Circular (AC) 61-107A, "Operations of Aircraft at Altitudes Above 25,000 Feet MSL," and issued an FAA notice, magazine article, and press release to promote the guidance.[90]

In 2011, we issued five safety recommendations to the FAA to require operators to address various aspects of flight crew initial and recurrent, hands-on, and aircraft-specific training on oxygen mask use, including Safety Recommendation A-11-89, which specifically addressed the procedures for establishing and maintaining communications when the oxygen masks are donned.[91] Safety Recommendation A-11-89 resulted from two investigations that identified crew communications difficulties while using their oxygen masks. The investigations also identified that flight crews were having difficulties properly performing the procedures during simulator sessions, particularly those that simulated a reduced visibility environment (such as smoke-obscured vision).

In response to Safety Recommendation A-11-89 (and others), the FAA stated in 2011 that it planned to issue a notice to principal operations inspectors to review their assigned operators' training programs and emergency checklists that address the use of oxygen masks and determine whether the operators should revise their

[90] As a result of the FAA's responsive actions, we classified Safety Recommendation A-00-111 Closed—Acceptable Action in 2004. The FAA canceled AC 61-107A about 9 years later.

[91] Safety Recommendation A-11-89 asked the FAA to require operators to include, during initial and recurrent training, aircraft-specific training on establishing and maintaining communications when the oxygen masks are donned. The other four recommendations (Safety Recommendations A-11-87, -88, -90, and -91) addressed requirements for full-face oxygen masks; tactile, hands-on training on the use of oxygen mask/goggle sets, to include the regulator and smoke venting features; the importance of setting oxygen masks to 100% before stowing them; and updates to operators' smoke, fire, or fumes checklists. Safety Recommendations A-11-87 through -91 are classified Closed—Unacceptable Action.

procedures. In 2013, the FAA stated that it decided not to issue the notice and did not plan to pursue rulemaking.

The FAA stated that it instead issued AC 120-80A, "In-Flight Fires," which contained a revision emphasizing the importance of flight crew initial and recurrent hands-on training on establishing and maintaining communications while using oxygen masks.[92] Because the FAA did not take action to require the training, as recommended, we classified Safety Recommendation A-11-89 Closed—Unacceptable Action on January 19, 2018.

The NTSB concludes that the circumstances of this accident and others highlight the need for hands-on, aircraft-specific crew training and procedures for the use of each type of oxygen system in an operator's fleet, including donning masks, communicating with them on, and reestablishing communications after removing masks. Ensuring flight crew proficiency with using emergency oxygen mask equipment could help reduce communications difficulties when performing the time-critical procedures to address the emergency that required its use, such as a rapid depressurization or smoke in the flight deck.

Although the NTSB continues to believe that Part 121 operators should be required to provide such hands-on, aircraft specific training, the FAA has previously declined to take such action. However, educating operators about the circumstance of this accident and others may encourage them to implement voluntary improvements to their training programs, similar to the improvements Alaska Airlines made to its program.

Therefore, the NTSB recommends that the FAA notify operators of the circumstances of this accident, and encourage them to review their flight crew training programs and ensure that they include hands-on, aircraft-specific training and procedures for each type of oxygen system in their fleet, to include establishing and maintaining communications when the oxygen masks are donned and removed while participating in realistic emergency procedures training scenarios.

2.6.2 Need for Portable Oxygen Bottle Design Standard Review

Portable oxygen masks are designed in accordance with FAA regulatory and technical standard order specifications for ensuring rapid donning while also prioritizing intuitive use, to include secure fit and time-critical emergency responses. As stated in section 2.2.1.2, the flight attendants who used the portable oxygen

[92] Both AC 120-80A and the revised and retitled version the FAA issued in 2023 (AC 120-80B, "Firefighting of General and High-Energy In-Flight Fires") contained only one sentence referencing flight crew training on establishing and maintaining communications while using oxygen masks (FAA 2014, 1; 2023, 1).

bottles to move through the cabin reported challenges opening and donning the mask. Although Alaska Airlines has since updated its flight attendant initial and recurrent training to provide a demonstration on how to remove from its packaging and don a portable oxygen bottle mask similar to the mask type used on the accident flight, the NTSB is concerned that users may not be able to easily and quickly open the packaging and don the masks during an emergency.

Of particular concern is that one flight attendant was unable to open the packaging without improvising a tool by using her identification badge to puncture it. This flight attendant also had difficulty uncoiling the tube and donning the mask, choosing to hold the mask over her mouth rather than secure it with the elastic strap.

Thus, the NTSB concludes that, although the portable oxygen bottles used by the flight attendants met FAA design standards, the difficulties the flight attendants encountered when using the masks, including the need to improvise a tool to open the packaging, suggest that the standards, the mask design, or both do not adequately consider ease of use and quick donning in an emergency.

Therefore, the NTSB recommends that the FAA review and revise, as necessary, the design standards that apply to portable oxygen bottle design to ensure that they adequately address ease of use and quick donning in an emergency situation, including considerations for the effort needed to remove the mask from its packaging.

2.6.3 Benefits of Cockpit Voice Recorder Data for Supporting Safety Improvements

2.6.3.1 Need for Effective Procedures for Preserving Cockpit Voice Recorder Data

Alaska Airlines' FOM specified that flight crews involved in an incident or accident were required, if possible, to pull the CVR and FDR circuit breakers as soon as possible after the airplane was secured; however, this did not occur after the accident flight. By the time maintenance personnel responded to the airplane to pull the CVR circuit breaker for the accident airplane's 2-hour CVR, the audio for the accident flight had been overwritten. As a result, the NTSB was unable to fully evaluate some flight deck environment events associated with the rapid depressurization.

As stated previously, the investigation determined that the pilots did not properly establish communications back to their headsets after removing their oxygen masks. However, the investigation was unable to determine from the available information whether factors other than the loud noises in the airplane contributed to the reported communications difficulties that occurred while the pilots were wearing their oxygen masks, such as the captain's and flight attendant A's reported inability to communicate with each other over the interphone despite multiple attempts.

Such a determination would support the development of recommendations for safety enhancements, which, depending on the reason for the difficulties, could involve equipment, procedural, or training solutions. Thus, the NTSB concludes that Alaska Airlines' procedures at the time of the accident were ineffective in ensuring that the CVR data were preserved from the accident flight, resulting in the loss of critical information for the investigation.

Had the postaccident procedural changes implemented by Alaska Airlines been in place at the time of the accident (see section 1.12.4.4), the CVR circuit breaker likely would have been pulled in time to preserve the cockpit audio from the accident. These changes placed responsibility not only on flight crews but also on operational personnel such as dispatch, flight operations, and maintenance control personnel, increasing the likelihood that the CVR circuit breaker would be pulled in a timely manner.

Aspects of the accident flight as it relates to preservation of CVR data were similar to those of many reportable events (that is, serious incidents that do not meet the injury or damage criteria to be classified as an accident), such as runway incursions, during which the aircraft is subsequently landed safely, and the CVR continues to operate until manually powered off.[93] The issue of operators not taking action to preserve CVR data immediately after the completion of a flight involving a reportable event has been a longstanding concern.

In August 2002, the NTSB issued Safety Recommendation A-02-24, urging the FAA to require operators to revise their procedures to specify that the CVR be deactivated, either manually or by automatic means, immediately upon completion of the flight, as part of an approved aircraft checklist procedure after a reportable event. In response, in April 2003, the FAA issued Notice 8400.48, "[CVR] Deactivation After a Reportable Event." This notice advised operators to add an approved aircraft checklist item to deactivate the CVR, manually or automatically, immediately upon completion of a flight with a reportable event.

[93] Title 14 *CFR* 830.5 defines various types of serious incidents that must be reported to the NTSB. These include air carrier operations involving landing or departing on a taxiway, incorrect runway, or other area not designed as a runway; air carrier operations involving a runway incursion that requires the operator of another aircraft or vehicle to take immediate action to avoid a collision; various types of in-flight malfunctions or failures of flight control, electrical, or hydraulic systems; loss of information from various types of cockpit displays, including primary flight displays and primary navigation displays; among other events requiring immediate notification.

In October 2003, we classified A-02-24 Closed—Acceptable Alternate Action, because the FAA notice met the intent of the recommendation for Part 121 and Part 135 operators, but not for Part 91 operators. Additionally, FAA AC 20-186, "Airworthiness and Operational Approval of [CVR] Systems," originally issued in 2016, provided further guidance, recommending—but not requiring—that operators incorporate CVR retention procedures into their maintenance and operational programs.

More than two decades after the issuance of A-02-24, the challenge of establishing consistent policies and procedures for CVR data preservation remains. For example, the CVR data for both airplanes involved in a runway incursion and overflight incident that occurred in Austin, Texas, on February 4, 2023, were overwritten as both airplanes continued to operate after the incident (NTSB 2024). As the circumstances of that incident and this accident show, despite existing guidance on preserving CVR data, operators still lack effective measures to safeguard CVR recordings after accidents and reportable events, resulting in the continued loss of critical information for investigations.

Therefore, the NTSB recommends that the FAA require operators of airplanes equipped with a CVR to incorporate guidance into company standard operating procedures, emergency protocols, and postincident and postaccident checklists—applicable to both flight crew and non-flight crew personnel—detailing actions to preserve CVR recordings as soon as practical after completion of a flight with a reportable event.

2.6.3.2 Need for 25-Hour Cockpit Voice Recorder Installations and Retrofits

In addition, the NTSB has long advocated for requirements for 25-hour CVRs, which would mitigate the risk of a CVR recording being overwritten. In October 2018, we issued Safety Recommendations A-18-30 and -31 based on investigations lacking access to relevant CVR data (NTSB 2018). These investigations included a July 2017 taxiway overflight incident in San Francisco, California, which had significant safety issues.[94] Also, following the previously referenced runway incursion and overflight incident that occurred in Austin, Texas, on February 4, 2023, we reiterated Safety Recommendation A-18-30 and superseded A-18-31 with A-24-9 (NTSB 2024).[95] The safety recommendations asked the FAA to take the following actions:

[94] For information about the taxiway overflight incident at San Francisco, see NTSB case number DCA17IA148.

[95] On May 29, 2024, the NTSB classified Safety Recommendation A-18-31 Closed—Unacceptable Action/Superseded because the FAA did not complete the requested action by January 1, 2024.

Require all newly manufactured airplanes that must have a CVR be fitted with a CVR capable of recording the last 25 hours of audio. (A-18-30)

Require retrofit of all CVRs on all airplanes required to carry both a CVR and a flight data recorder with a CVR capable of recording the last 25 hours of audio. (A-24-9)

In December 2023, the FAA addressed Safety Recommendation A-18-30 by publishing a notice of proposed rulemaking (NPRM) proposing that newly manufactured aircraft be equipped with CVRs capable of recording 25 hours of data. If issued, a final rule based on the NPRM will likely satisfy this recommendation, which is currently classified Open—Acceptable Response. However, ee do not fully support the NPRM because it did not propose a similar requirement to retrofit existing airplanes required to carry a CVR and an FDR, as discussed in Safety Recommendation A-24-9. Accordingly, this recommendation is currently classified Open—Unacceptable Response.

On May 16, 2024, the FAA Reauthorization Act of 2024 became law. The act required 25-hour CVRs for aircraft operated under Part 121, other transport-category airplanes that were type certificated with a seating capacity of 30 or more passengers, and cargo derivatives of such airplanes that are operated under other regulations. The act specified that newly manufactured aircraft would be equipped with 25-hour CVRs starting 1 year after the date of the act. Also, the act specified that affected operators were to retrofit their aircraft with a 25-hour CVR no later than 6 years after the date of the act. In addition, the act required the FAA, within 3 years of the date of the act, to issue a final rule to update applicable regulations to conform to the CVR retrofit requirement for existing aircraft.

The airplane involved in this accident would not be subject to the proposed rulemaking announced by the FAA in December 2023 but would be subject to the 6-year retrofit requirement in the FAA Reauthorization Act of 2024. Although the statutory requirement for 25-hour CVRs on newly manufactured airplanes is in effect, the FAA has not yet issued a final rule to incorporate this provision into the regulations.

Since the original issuance of our CVR recommendations in 2018, more than 20 of our investigations (including this investigation) have been negatively affected by overwritten CVR data (see table 4).

Table 4. Investigations since October 2018 negatively affected by overwritten CVR data.

Date	NTSB case	Location	Event type
2/25/2025	DCA25LA120	Chicago, Illinois	Runway incursion
1/24/2025	DCA25LA093	Dabouzra, Côte d'Ivoire	Flight control system malfunction
9/25/2024	DCA24LA318	Chicago, Illinois	Landed wrong runway

Date	NTSB case	Location	Event type
9/12/2024	DCA24FA300	Nashville, Tennessee	Runway incursion
4/17/2024	DCA24FA164	Queens, New York	Runway incursion
2/10/2024	DCA24LA097	Kelsey, New York	Turbulence
1/5/2024	DCA24MA063	Portland, Oregon	Rapid depressurization
11/30/2023	DCA24LA034	Kahului, Hawaii	Ground collision
9/25/2023	DCA23LA462	Caribbean Sea	Turbulence
8/11/2023	OPS23FA010	San Diego, California	Runway incursion (delayed notification)
2/27/2023	DCA23LA192	Boston, Massachusetts	Runway incursion (delayed notification)
2/22/2023	DCA23LA185	Burbank, California	Runway incursion
2/16/2023	DCA23LA179	Sarasota, Florida	Runway incursion (delayed notification)
2/4/2023	DCA23FA149	Austin, Texas	Runway incursion
1/23/2023	DCA23LA133	Honolulu, Hawaii	Runway incursion
1/13/2023	DCA23LA125	New York, New York	Runway incursion
8/6/2022	DCA22LA178	Atlanta, Georgia	Hard landing
7/7/2022	WPR22LA284	San Francisco, California	Loss of control in flight
2/15/2020	ENG20LA016	Sacramento, California	Electrical system malfunction
12/18/2019	DCA20CA043	Disputanta, Virginia	Turbulence encounter
11/6/2019	DCA20IA014	Atlanta, Georgia	Loss of control in flight
6/15/2019	DCA19CA167	Newark, New Jersey	Hard landing

Note: How long the CVR continued to operate after each event is not known for every investigation, such as the delayed notification events.

As the number of events listed in table 4 shows, the potential for data to be overwritten on a 2-hour recorder persists. Thus, the NTSB concludes that the circumstances of this accident and others show that CVRs with a 25-hour recording capability are necessary because valuable information continues to be overwritten on CVRs that are designed to record only 2 hours of audio data. Therefore, the NTSB reiterates Safety Recommendation A-24-9 to the FAA.

Further, the NTSB notes that nearly 18 months have passed since the FAA released the NPRM to require 25-hour CVRs on newly manufactured airplanes, and, as stated previously, although the statutory requirement is in place, the FAA has not yet issued a final rule to incorporate the provision into regulations. Therefore, the NTSB reiterates Safety Recommendation A-18-30.

2.6.4 Safety Benefits of Child Restraint Systems

The caregivers of the three lap-held children on the accident flight were seated five or more rows away from the fuselage hole (at row 26) and were able to secure their children during the rapid depressurization event. However, passengers seated closer to the hole experienced the most adverse effects of the event, including the loss of clothing and belongings that were forcefully pushed out of the hole as the higher pressure air in the cabin escaped. Had the airplane been at a higher altitude (with a greater pressure differential) when the separation of the left MED plug occurred, the likelihood that a caregiver seated near the hole could have safely restrained a lap-held child is reduced. Other airplane accidents and incidents have occurred in which caregivers were unable to hold lap-held children securely.[96]

There is widespread consensus among the transportation safety and medical communities that it is safest for children less than 2 years old to be seated in their own seat on an airplane, using an appropriate CRS, such as a car seat that is also approved for airplane use. For example, the American Academy of Pediatrics has stated that "the safest place for a child under 2 on an airplane is in a car seat, not on a parent's lap," and that, "if there is turbulence, or worse, you may not be able to protect your baby in your arms" (NTSB 2021, 58-9). The use of a CRS provides an equivalent level of safety for infants and children as that afforded to adult passengers wearing seat belts.

The NTSB has a longstanding history of interest in the safety of lap-held children on board airplanes. For more than three decades, we have recommended that the FAA require the use of a CRS appropriate to the child's size and weight.[97] However, in response to these recommendations, the FAA has consistently declined to mandate CRS usage for children under the age of 2. Instead, the FAA has emphasized the actions it has taken to increase voluntary CRS usage, including providing information on the FAA website and conducting outreach via social media. Thus, the NTSB concludes that the FAA's emphasis on increasing voluntary usage of CRSs, rather than mandating their use as we have long recommended, has continued

[96] For example, in 2017, an Embraer 170 airplane encountered turbulence about 25 miles from its destination, and several passengers were thrown into their passenger service units, and one lap-held child was thrown several rows away from her mother but was uninjured (see NTSB case DCA17CA155). In 1994, a Douglas DC-9-31 collided with trees and crashed during a missed approach procedure. The NTSB determined that a 9-month-old lap-held child who sustained fatal injuries during the impact sequence after her mother was unable to maintain secure hold of her likely would have survived if she had been secured by a CRS (NTSB 1995,114).

[97] Safety Recommendation A-90-78, issued May 30, 1990, recommended that the FAA "revise 14 *CFR* 91, 121, and 135 to require that all occupants be restrained during takeoff, landing, and turbulent conditions, and that all infants and small children below the weight of 40 pounds and under the height of 40 inches be restrained in an approved child restraint system appropriate to their height and weight." This recommendation was superseded by Safety Recommendation A-95-51 in 1995, which recommended that the FAA "revise 14 *CFR* Parts 91, 135, and 121 to require that all occupants be restrained during takeoff, landing, and turbulent conditions, and that all infants and small children be restrained in a manner appropriate to their size." Safety Recommendation A-95-51 was classified Closed—Unacceptable Action on December 13, 2006. Safety Recommendation A-10-123, issued in 2010, recommended that the FAA "amend 14 *CFR* Parts 121 and 135 to require each person who is less than 2 years of age to be restrained in a separate seat position by an appropriate CRS during takeoff, landing, and turbulence." Safety Recommendation A-10-123 was classified Closed—Unacceptable Action on November 4, 2013.

to allow children under the age of 2 years to travel on board aircraft at a lower level of safety than that of seat belt-wearing adult passengers.

In our 2021 safety research report on preventing turbulence-related injuries, we noted that, because the FAA has not evaluated the effects of its public education campaign, it is difficult to accurately determine trends in the amount of voluntary CRS usage, to identify operational impediments to CRS usage, or to evaluate the effects of public education or industry efforts on CRS usage. We concluded that such analyses require applicable data and that researching the factors that affect caregivers' decisions about whether to use a CRS would inform and improve government and industry efforts to increase the voluntary use of CRSs (NTSB 2021, 59).

As a result, we recommended that the FAA do the following:

> Conduct a study to determine the factors that affect caregivers' decisions about the use of child restraint systems (CRSs) when traveling on a Title 14 *Code of Federal Regulations* Part 121 air carrier airplane with children under the age of 2 and to understand the challenges associated with using CRSs; publish the study findings. (A-21-40)
>
> After the action in Safety Recommendation A-21-40 is completed, use the study findings to direct the Federal Aviation Administration's efforts to increase child restraint system usage. (A-21-41)

We also recommended that Airlines for America, the National Air Carrier Association, and the Regional Airline Association each do the following:

> Coordinate with your member airlines to develop and implement a program to increase child restraint system (CRS) usage in airplanes; this effort should include collecting data to determine the program's effectiveness at increasing CRS usage. (A-21-45)

At the time of this report, the FAA and the industry groups had initiated responsive action to these recommendations, but some planned actions are not yet completed. As a result, Safety Recommendations A-21-40, -41, and -45 are classified Open—Acceptable Response.

We continue to believe that the safest place for a child under the age of 2 on board an aircraft is in a CRS. For accidents involving such events as severe turbulence, loss of control during landing, and rapid depressurization, the use of CRS could be the difference between no injury and a tragic loss of life. Thus, the NTSB concludes that, although none of the three lap-held children on board the airplane sustained injury, the circumstances of this accident and others show that the potential for severe injury or death exists for children less than 2 years old who are not secured in a CRS appropriate to their size and weight. Therefore, the NTSB reiterates Safety Recommendations A-21-40, -41, and -45.

3 Conclusions

3.1 Findings

1. The flight and cabin crewmembers were certificated and qualified in accordance with applicable federal regulations and Alaska Airlines' requirements.

2. There was no evidence that, since delivery, Alaska Airlines performed any maintenance, inspection, or retrofit work on the airplane that would involve opening the left mid exit door plug.

3. The left mid exit door plug displaced incrementally upward during previous flights; then, during the accident flight, it displaced upward to the point of stop pin to stop pad instability, then upward, outboard, and aft as it separated from the fuselage.

4. The evidence of the upward displacement of the left mid exit door plug before the accident flight would not have been readily detectable by a flight crewmember performing a routine preflight walkaround inspection.

5. The airplane's cabin pressurization system operated as designed both before and after the left mid exit door (MED) plug separated, and there was no evidence that the previous pressurization system AUTO FAIL light illumination events were associated with the left MED plug's upward displacement during previous flights.

6. The flight crew's immediate actions to don their oxygen masks after the rapid depressurization and use the "CABIN ALTITUDE or Rapid Depressurization" checklist were consistent with company procedures, their decision to descend the airplane and return to the departure airport was timely and appropriate, and they demonstrated effective high-workload management and task allocation appropriate for a two-person crew to safely handle the emergency.

7. The teamwork and complementary duties of the flight crew, which occurred during the emergency, reinforce the necessity for a minimum crew of two pilots, as specified in the airplane type certificate, as well as Title 14 *Code of Federal Regulations* Part 121 operating rules.

8. Although the flight crew did not perform the procedures to switch communications back to their headsets after removing their oxygen masks, this had no adverse effect on their subsequent safe landing of the airplane.

9. Flight attendant A's difficulty communicating with the flight crew and challenges communicating with the other cabin crewmembers did not impede the cabin crew's ability to execute cabin procedures and effectively ensure the safety of the passengers, including unaccompanied minors, after the rapid depressurization and during the descent and return to the airport.

10. All flight attendants and passengers were able to use the overhead oxygen masks to obtain oxygen after the rapid depressurization, and the portable oxygen bottles provided oxygen to the two flight attendants who used them to move through the cabin.

11. The absence of bolt contact damage or deformation around the holes associated with the vertical movement arrestor bolts and upper guide track bolts indicates that the four bolts that should have been installed to prevent the left mid exit door plug's upward movement were missing before the plug moved upward off the stop pads.

12. The left mid exit door plug's vertical movement arrestor bolts, upper guide track bolts, and associated hardware were installed before the fuselage was delivered to Boeing but subsequently removed during the manufacturing process when the plug was opened to facilitate additional work.

13. Neither the door team manager nor any of the door team personnel on duty when the left mid exit door (MED) plug was opened had any experience with opening an MED plug, and none said they had any knowledge of who opened it.

14. Whoever opened the left mid exit door plug did not generate a removal record, which increased the risk that the closure would not be performed properly due to the absence of the documented steps for the bolts and hardware to be reinstalled and for a quality assurance inspection to verify that the installation was restored to accepted condition.

15. Boeing Commercial Airplanes' Business Process Instruction "Perform Part or Assembly Removal" lacked clarity, conciseness, and ease of use necessary to be an effective tool for manufacturing personnel to consistently and correctly determine when and how to generate a removal record.

16. Boeing Commercial Airplanes' on-the-job training was unstructured, undocumented, and focused primarily on routine build tasks, which decreased the likelihood that door team personnel with limited exposure to nonroutine tasks would be able to correctly perform the process for opening a mid exit door plug, including generating the required removal record.

17. Only door team personnel were allowed to perform work on doors and mid exit door (MED) plugs, but none were on duty at the time the left MED plug was closed.

18. Due to the absence of a removal record indicating that the left mid exit door plug installation had been disturbed, no quality assurance inspection of the plug closure was performed.

19. The postaccident design enhancement of the mid exit door (MED) plug, if certified by the Federal Aviation Administration and implemented by Boeing Commercial Airplanes, will help ensure the complete closure of an MED plug following opening or removal.

20. Because Boeing Commercial Airplanes did not conduct a change management assessment to identify and address the risks associated with using a workforce with reduced experience, including hiring many with little or no previous manufacturing experience, it missed an opportunity to proactively implement mitigations to ensure quality standards were maintained.

21. Although accepted by the Federal Aviation Administration, Boeing Commercial Airplanes' corrective actions were ineffective to address the persistent deficiencies with Boeing's Business Process Instruction "Perform Part or Assembly Removal," which had a documented history of compliance issues for at least 10 years before the accident.

22. Although Boeing Commercial Airplanes' short stamp process for deferred or traveled work does not negate the need to generate a required removal record for disturbed installations, had the short stamp process been correctly applied on Boeing Installation Plan "OK to Install Blankets" for the accident airplane, it may have provided an opportunity for personnel to detect the left mid exit door plug's missing bolts and attachment hardware.

23. The Federal Aviation Administration's compliance and enforcement surveillance, audit planning assessments, and records systems were deficient and lacked the functionality necessary to identify repetitive and systemic discrepancies and nonconformance issues with Boeing Commercial Airplanes' Business Process Instruction "Perform Part or Assembly Removal," including previous instances of undocumented part removals.

24. Boeing Commercial Airplanes' quality escape guidance, which focused on components rather than the actions of people performing tasks, did not

adequately address controls for human error, leaving a gap in Boeing's ability to identify and build effective mitigation strategies.

25. In the 2 years before the accident airplane's production, Boeing Commercial Airplanes' voluntary safety management system was an immature program that lacked formal Federal Aviation Administration oversight and did not proactively identify the risk of the quality escape that occurred.

26. Having a fully developed safety management system, implemented at every level of the quality management and production process, will provide Boeing Commercial Airplanes with a systematic approach to proactively identifying and managing the human risks associated with aircraft production.

27. Due to the mixed perspectives provided by the relatively small sample size of employees interviewed about the accident airplane's left mid exit door plug and the prolonged work stoppage at Boeing Commercial Airplanes that precluded the National Transportation Safety Board from conducting a broader safety culture survey, an assessment of Boeing's safety culture, including whether adverse pressure existed on the production line, could not be performed as part of this investigation.

28. For future implementation of Boeing Commercial Airplanes' regulatory safety management system and integration into its quality management system to be successful, accurate and ongoing data about its safety culture is needed.

29. While hands-on oxygen mask simulator training was provided to the flight crew before the accident, it lacked realistic scenario-based exercises and, therefore, failed to adequately prepare them for potential real-world events.

30. The circumstances of this accident and others highlight the need for hands-on, aircraft-specific crew training and procedures for the use of each type of oxygen system in an operator's fleet, including donning masks, communicating with them on, and reestablishing communications after removing masks.

31. Although the portable oxygen bottles used by the flight attendants met Federal Aviation Administration design standards, the difficulties the flight attendants encountered when using the masks, including the need to improvise a tool to open the packaging, suggest that the standards, the mask design, or both do not adequately consider ease of use and quick donning in an emergency.

32. Alaska Airlines' procedures at the time of the accident were ineffective in ensuring that the cockpit voice recorder data were preserved from the accident flight, resulting in the loss of critical information for the investigation.

33. The circumstances of this accident and others show that cockpit voice recorders (CVR) with a 25-hour recording capability are necessary because valuable information continues to be overwritten on CVRs that are designed to record only 2 hours of audio data.

34. The Federal Aviation Administration's emphasis on increasing voluntary usage of child restraint systems, rather than mandating their use as the National Transportation Safety Board has long recommended, has continued to allow children under the age of 2 years to travel on board aircraft at a lower level of safety than that of seat belt-wearing adult passengers.

35. Although none of the three lap-held children on board the airplane sustained injury, the circumstances of this accident and others show that the potential for severe injury or death exists for children less than 2 years old who are not secured in a child restraint system appropriate to their size and weight.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was the in-flight separation of the left mid exit door (MED) plug due to Boeing Commercial Airplanes' failure to provide adequate training, guidance, and oversight necessary to ensure that manufacturing personnel could consistently and correctly comply with its parts removal process, which was intended to document and ensure that the securing bolts and hardware that were removed from the left MED plug to facilitate rework during the manufacturing process were reinstalled. Contributing to the accident was the Federal Aviation Administration's ineffective compliance enforcement surveillance and audit planning activities, which failed to adequately identify and ensure that Boeing addressed the repetitive and systemic nonconformance issues associated with its parts removal process.

4 Safety Recommendations

4.1 New Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following new safety recommendations.

To the Federal Aviation Administration:

Once you complete the certification of Boeing Commercial Airplanes' design enhancement for ensuring the complete closure of Boeing 737 mid exit door (MED) plugs following opening or removal, issue an airworthiness directive to require that all in-service MED plug-equipped airplanes be retrofitted with the design enhancement. (A-25-15)

Revise your compliance enforcement surveillance system to ensure that it provides the necessary functionality for Federal Aviation Administration managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes. (A-25-16)

Revise your audit planning activities to ensure that they provide the necessary functionality for Federal Aviation Administration managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes. (A-25-17)

Revise your records systems to ensure that they provide the necessary records for Federal Aviation Administration managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes. (A-25-18)

Once the actions in Safety Recommendations A-25-16 through -18 are completed, develop guidance for Federal Aviation Administration managers and inspectors who provide oversight of production approval holders on how to identify, record, track, and effectively address repetitive and systemic discrepancies and nonconformance issues, to include strategies for assessing the effectiveness of corrective actions taken by the production approval holder during the previous year when developing next year's certificate management plan. (A-25-19)

Once the actions in Safety Recommendation A-25-19 are completed, provide Federal Aviation Administration managers and inspectors who provide oversight of production approval holders with recurrent training on how to identify, record, track, and effectively address repetitive and systemic discrepancies and nonconformance issues, to include strategies for assessing the effectiveness of corrective actions taken by the production approval holder during the previous year when developing the next year's certificate management plan. (A-25-20)

Retain historical compliance enforcement surveillance and audit records older than 5 years and provide Federal Aviation Administration managers and inspectors access to these records to enhance their oversight planning for production approval holders. (A-25-21)

Convene an independent panel to conduct a comprehensive review of Boeing Commercial Airplanes' safety culture. The findings should be used to enhance the ongoing development of Boeing's regulatory safety management system (SMS) and the integration of its SMS into its broader quality management system. (A-25-22)

Notify operators of the circumstances of the accident involving Alaska Airlines flight 1282, and encourage them to review their flight crew training programs and ensure that they include hands-on, aircraft-specific training and procedures for each type of oxygen system in the operators' fleet, to include establishing and maintaining communications when the oxygen masks are donned and removed while participating in realistic emergency procedures training scenarios. (A-25-23)

Review and revise, as necessary, the design standards that apply to portable oxygen bottle design to ensure that they adequately address ease of use and quick donning in an emergency situation, including considerations for the effort needed to remove the mask from its packaging. (A-25-24)

Require operators of airplanes equipped with a cockpit voice recorder (CVR) to incorporate guidance into company standard operating procedures, emergency protocols, and postincident and postaccident checklists—applicable to both flight crew and non-flight crew personnel—detailing actions to preserve CVR recordings as soon as practical after completion of a flight with a reportable event. (A-25-25)

To The Boeing Company:

Continue the certification process for the design enhancement for mid exit door plugs to ensure that, once the design enhancement is certified, all applicable newly manufactured airplanes are equipped with the enhancement. (A-25-26)

Once the design enhancement for mid exit door (MED) plugs is certified, issue a service bulletin to address retrofitting in-service MED plug-equipped airplanes with the design enhancement. (A-25-27)

Apply your updated safety risk management process to current and future revisions to Business Process Instruction "Perform Part or Assembly Removal" to ensure that it provides clear and concise guidance for determining when a removal record is needed. (A-25-28)

Develop recurrent training on Business Process Instruction "Perform Part or Assembly Removal" for Boeing manufacturing personnel that emphasizes the importance of removal records for product safety, prepares personnel to consistently and correctly determine when a removal record is needed, and ensures that a removal record is generated when required. (A-25-29)

Develop a structured on-the-job training program that identifies and defines tasks necessary for manufacturing personnel to be considered fully qualified in their job series and includes a grading system for trainers and trainees to track progress and determine competence.(A-25-30)

Document and archive the results of training provided and received as part of the program recommended in Safety Recommendation A-25-30 to support future data analysis. (A-25-31)

Revise your safety risk management process to ensure that it 1) identifies the root causes of manufacturing process compliance issues, like the persistent deficiencies with Business Process Instruction "Perform Part or Assembly Removal" and other production process inconsistencies identified in this investigation, and 2) evaluates the effectiveness of corrective actions. (A-25-32)

As you integrate your quality management system and safety management system, develop a process that can identify escapes that result from human error, assess them using a system specifically designed to identify factors that contribute to such errors, and implement effective mitigation strategies. (A-25-33)

4.2 Previously Issued Recommendations Reiterated in This Report

The National Transportation Safety Board reiterates the following safety recommendations.

To the Federal Aviation Administration:

Require all newly manufactured airplanes that must have a cockpit voice recorder (CVR) be fitted with a CVR capable of recording the last 25 hours of audio. (A-18-30)

Require retrofit of all cockpit voice recorders (CVR) on all airplanes required to carry both a CVR and a flight data recorder with a CVR capable of recording the last 25 hours of audio. (A-24-9)

Conduct a study to determine the factors that affect caregivers' decisions about the use of child restraint systems (CRSs) when traveling on a Title 14 Code of Federal Regulations Part 121 air carrier airplane with children under the age of 2 and to understand the challenges associated with using CRSs; publish the study findings. (A-21-40)

After the action in Safety Recommendation A-21-40 is completed, use the study findings to direct the Federal Aviation Administration's efforts to increase child restraint system usage. (A-21-41)

To the Airlines for America, the National Air Carrier Association, and the Regional Airline Association:

Coordinate with your member airlines to develop and implement a program to increase child restraint system (CRS) usage in airplanes; this effort should include collecting data to determine the program's effectiveness at increasing CRS usage. (A-21-45)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JENNIFER L. HOMENDY
Chairwoman

MICHAEL GRAHAM
Member

THOMAS CHAPMAN
Member

J. TODD INMAN
Member

Report Date: June 24, 2025

Board Member Statements

Member Michael Graham filed the following concurring statement on June 30, 2025

As the findings of this report indicate, and as the probable cause suggests, Boeing Commercial Airplanes (Boeing) had no shortage of systemic issues in the leadup to Flight 1282 across numerous departments, teams, and levels of leadership. While eliminating all risk with such complex aircraft production is nearly impossible, Boeing's failures across its training, guidance, voluntary safety management system, quality management system, and internal auditing compromised the safety of the 737 production line in Renton. Even if the removal of the left mid exit door (MED) plug in Renton had been properly documented and the removed bolts properly reinstalled on the accident airplane, I am skeptical Boeing's systems at the time were equipped to catch these types of errors and would have successfully prevented a similar accident.

To that end, we issued nine recommendations to Boeing as a result of this investigation. These recommendations include implementing a design enhancement for MED plugs, revising Business Process Instruction (BPI) "Perform Part or Assembly Removal" to ensure clarity and brevity for employees, revising training programs, and improving the safety risk management process.

Prior to these recommendations formally being issued, and prior to this report's publication, Boeing has taken at least 20 actions – many detailed in section 1.12.2 of the report – to address the myriad of issues that plagued their Renton facility prior to this accident. Many of these corrective actions, while applicable to the door team on the 737 production line in Renton, extend far beyond one team or one production line. For example, Boeing has since revised the BPI "Perform Part or Assembly Removal," incorporated additional training on when removal documentation is required, and ensured that only personnel who have completed this additional training are allowed to initiate a removal. Additionally, they developed their Product Safety and Quality Plan, which includes six key performance indicators – such as how much work travels to factory rollout and total rework hours – that will help identify systemic issues early on so they can be rectified. The company has also implemented their "move ready" process across its production lines to ensure safety risk assessments are conducted at each stage of assembly, incorporated additional conformance inspections to nine critical build points on the 737 production line, issued alerts on removals and rework that were signed by all factory employees to ensure their acknowledgement, and instituted a more accessible employee reporting tool "Speak Up."

While we will continue to monitor Boeing's progress on fulfilling the recommendations we have adopted in this report, it is clear that Boeing not only improved their processes for the circumstances surrounding this accident, but they are focused on improving safety culture across their entire commercial aviation enterprise. Safety is not stagnant;

it is always evolving. I hope Boeing will take our recommendations seriously and continue to incorporate improvements to their safety culture to prevent a similar accident from reoccurring.

Michael Graham

Member Thomas Chapman filed the following concurring statement on June 26, 2025. Member Michael Graham joined in this statement.

I concur and join in the Board's unanimous adoption of the investigation report.

There are numerous lessons to be learned from this investigation, and I commend our team for their outstanding work. One of the issues highlighted is of particular concern to me – that is, child restraint systems.

There were three small children onboard Flight 1282 who were flying unrestrained and without a seat – so-called "lap children." Very thankfully, none of those children were seriously harmed. But it doesn't take much to imagine a more devastating outcome.

With this report, we are reiterating our 2021 recommendation calling on the leading airline industry trade associations to coordinate with their member airlines to develop and implement a program to increase usage of child restraint systems. I was an advocate for our 2021 recommendation, and I support our action to reiterate the recommendation. Of course, the need for it stems from FAA's minimalist approach to encouraging the use of child restraint systems.

FAA has long declined to require child restraint systems for young children. By regulation, the FAA says it's okay for young children under the age of two to travel by air while seated unsecured in an older passenger's lap. For parents lacking further information, FAA's *explicit* authority allowing lap children to fly unsecured implies the practice is safe – because, after all, the agency responsible for regulating air safety says it's okay.

The existing regulatory structure calls on parents or other caregivers to override FAA's implied safety judgment and substitute their own.

Unfortunately, families can only make the safest choice if they know enough to understand the serious risk to which they are exposing their children. And FAA has made little effort to educate the public about the risk to "lap children" – a risk which FAA acknowledges but has declined to regulate.

We need to keep after the folks at FAA. They have it wrong when it comes to the safety of young children, and we should remind them at every opportunity.

Meanwhile, the premise of our 2021 recommendation to the airline trade associations is that we haven't so far been able to count on FAA to do the right thing. We have to look directly to the airlines to help better inform parents and caregivers of the risks associated with young children flying unsecured. I urge them to take our recommendation to heart and help to ensure that this dangerous gap in safety is addressed.

Thomas Chapman

Member J. Todd Inman filed the following concurring statement on July 1, 2025

I concur with the findings, probable cause, and recommendations adopted by the Board in the June 24, 2025, Board meeting regarding the investigation into the accident involving Alaska Airlines Flight 1282. I want to thank the NTSB staff for their diligent, methodical, and exhaustive work on this complex and high-profile investigation. Their commitment to thorough, fact-based analysis has once again served public interest and aviation safety with distinction.

Comments on FAA Oversight

While the Boeing Company has received a tremendous amount of attention for their role in using a less-than-optimal manufacturing process that resulted in a final product that was flawed, it is important that the FAA receives its fair share of attention as the regulator responsible for conducting oversight and design certification. Between the current issues with the CFM Leap engine, the FAA not providing enough inspectors to cover all shifts on the Boeing manufacturing floor, and not sharing critical information on new systems with operators such as the MCAS system and cockpit doors being designed to automatically open during a rapid decompression event, the entire aircraft certification and oversight processes of the FAA should be examined for efficacy and safety. The FAA is a critical part of the puzzle that is aviation safety, and NTSB findings are consistently identifying a lack of effective processes used internally by the FAA.

The FAA must evolve toward a model that identifies risk trends earlier, enforces accountability more effectively, and ensures that all certificate holders – regardless of size or reputation – adhere to the highest standards.

Comments on SMS

As we discussed, this investigation underscores the vital importance of Safety Management Systems (SMS) across the entire aviation ecosystem – not just within airlines, but within manufacturers, maintenance organizations, and regulatory bodies. An effective SMS is not a paper exercise; it is a dynamic, living framework that requires leadership commitment, robust internal communication, and constant self-assessment. I believe Boeing is working and truly wishes to improve their SMS and I look forward to seeing it mature. But I would be remiss in not offering this has been an evolution of over ten years. We must stop seeing failures and silos in not only the regulators but the manufacturing systems. America's aviation system has become one of the safest in the world based on the sharing of information, however investigations recently show we are not making considerable gains in that momentum.

I believe it is imperative to mention that with the Boeing acquisition of Spirit Aerosystems; it is vital to incorporate them in these SMS plans to ensure a seamless and safe transition.

It is also a reminder of why redundancy and layered defenses – the so-called “Swiss cheese model” of accident prevention – remain critical. No single error should be able to result in a catastrophic outcome. In this case, multiple layers of the system failed: from the initial maintenance actions and documentation to quality assurance, to oversight. When holes in the cheese align, disaster follows. As I mentioned in the Board meeting, this could have resulted in tragedy if the event had taken place over the Pacific.

Comments on Party Process

This investigation highlights the enduring value of the NTSB’s party process, which allows us to gather critical data from a wide range of stakeholders while maintaining our independence and analytical rigor. The collaboration and transparency inherent in that process are essential to uncovering systemic issues that could otherwise remain hidden. All stakeholders have an interest in improving safety, and working alongside the NTSB provides the best opportunity to develop meaningful and lasting recommendations.

As we have seen, lives depend on maintaining a safe aircraft manufacturing process from all stakeholders. I urge all parties — government and industry alike — to take swift and sustained action to prevent another avoidable mishap like Flight 1282.

J. Todd Inman

Appendixes

Appendix A: Investigation and Hearing

Investigation

The National Transportation Safety Board (NTSB) was initially notified of this accident on January 5, 2024, about 1940 eastern standard time. A go-team departed Washington, DC, on January 6, 2024, about 1215 eastern standard time and arrived on scene in Portland, Oregon, about 1630 Pacific standard time. Chairwoman Jennifer Homendy accompanied the team to Portland.

The following investigative teams were formed: Operations, Structures, Materials/Metallurgy, Systems, and Survival Factors/Cabin Safety. While the investigative team was in Portland, specialists were assigned to conduct the readout of the flight data recorder and transcribe the cockpit voice recorder (CVR) at the NTSB's laboratory in Washington, DC. The CVR audio for the accident flight was overwritten, so a transcription was not produced. In addition, a Manufacturing and Human Performance group was formed and traveled to Seattle, Washington.

Parties to the investigation were the Federal Aviation Administration (FAA), Alaska Airlines, Air Line Pilots Association (ALPA), Association of Flight Attendants – CWA (AFA), The Boeing Company, Spirit AeroSystems, and the International Association of Machinists & Aerospace Workers (IAM).

Investigative Hearing

An investigative hearing was held from August 6 to 7, 2024, in Washington, DC. Chairwoman Homendy served as the Chair of the Board of Inquiry for the en banc hearing. The issues discussed at the investigative hearing were the Boeing 737-9 manufacturing process and inspections, the events surrounding the opening and closing of the left mid exit door plug, Boeing's quality management system and safety management system, and FAA oversight of the Boeing Commercial Airplanes business unit of The Boeing Company. Parties to the hearing were the FAA, Alaska Airlines, ALPA, AFA, Spirit AeroSystems, and IAM.

Appendix B: Consolidated Recommendation Information

Title 49 *United States Code* 1117(b) requires the following information on the recommendations in this report.

For each recommendation–

(1) a brief summary of the Board's collection and analysis of the specific accident investigation information most relevant to the recommendation;

(2) a description of the Board's use of external information, including studies, reports, and experts, other than the findings of a specific accident investigation, if any were used to inform or support the recommendation, including a brief summary of the specific safety benefits and other effects identified by each study, report, or expert; and

(3) a brief summary of any examples of actions taken by regulated entities before the publication of the safety recommendation, to the extent such actions are known to the Board, that were consistent with the recommendation.

To the Federal Aviation Administration

A-25-15

Once you complete the certification of Boeing Commercial Airplanes' design enhancement for ensuring the complete closure of Boeing 737 mid exit door (MED) plugs following opening or removal, issue an airworthiness directive to require that all in-service MED plug-equipped airplanes be retrofitted with the design enhancement.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.12.2.7 Ongoing Work on Mid Exit Door Plug Design Enhancement Certification and 2.3.2 Incomplete Closure of Left Mid Exit Door Plug. Information supporting (b)(1) can be found on pages 76 and 93; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 76 and 93.

A-25-16

Revise your compliance enforcement surveillance system to ensure that it provides the necessary functionality for Federal Aviation Administration managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.3.3 Business Process Instruction "Perform Part or Assembly Removal," 1.11.2.4 Federal Aviation Administration Oversight of Boeing Production Processes and 2.4.2.2 Ineffective Federal Aviation Administration Oversight. Information supporting (b)(1) can be found on pages 64-69 and 97-100; (b)(2) and (b)(3) are not applicable.

A-25-17

Revise your audit planning activities to provide the necessary functionality for Federal Aviation Administration managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes.

Information that addresses the requirements of 49 USC 1117(b), as applicable, can be found in sections 1.11.2.3.3 Business Process Instruction "Perform Part or Assembly Removal," 1.11.2.4 Federal Aviation Administration Oversight of Boeing Production Processes and 2.4.2.2 Ineffective Federal Aviation Administration Oversight. Information supporting (b)(1) can be found on pages 64-69 and 97-100; (b)(2) and (b)(3) are not applicable.

A-25-18

Revise your records systems to ensure that they provide the necessary records for Federal Aviation Administration managers and inspectors overseeing production approval holders to effectively identify, record, track, and resolve recurring and systemic discrepancies and nonconformance issues, including those related to specific manufacturing processes.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.3.3 Business Process Instruction "Perform Part or Assembly Removal," 1.11.2.4 Federal Aviation Administration Oversight of Boeing Production Processes and 2.4.2.2 Ineffective Federal Aviation Administration Oversight. Information supporting (b)(1) can be found on pages 64-69 and 97-100; (b)(2) and (b)(3) are not applicable.

A-25-19

Once the actions in Safety Recommendations A-25-16 through -18 are completed, develop guidance for Federal Aviation Administration managers and inspectors who provide oversight of production approval holders on how to identify, record, track, and effectively address repetitive and systemic discrepancies and nonconformance issues, to include strategies for assessing the effectiveness of corrective actions taken by the production approval holder during the previous year when developing next year's certificate management plan.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.4 Federal Aviation Administration Oversight of Boeing Production Processes and 2.4.2.2 Ineffective Federal Aviation Administration Oversight. Information supporting (b)(1) can be found on pages 64-69 and 97-100; (b)(2) and (b)(3) are not applicable.

A-25-20

Once the actions in Safety Recommendation A-25-19 are completed, provide Federal Aviation Administration managers and inspectors who provide oversight of production approval holders with recurrent training on how to identify, record, track, and effectively address repetitive and systemic discrepancies and nonconformance issues, to include strategies for assessing the effectiveness of corrective actions taken by the production approval holder during the previous year when developing next year's certificate management plan.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections1.11.2.3.3 Business Process Instruction "Perform Part or Assembly Removal," 1.11.2.4 Federal Aviation Administration Oversight of Boeing Production Processes, and 2.4.2.2 Ineffective Federal Aviation Administration Oversight. Information supporting (b)(1) can be found on pages 64-69 and 97-100; (b)(2) and (b)(3) are not applicable.

A-25-21

Retain historical compliance enforcement surveillance and audit records older than 5 years and provide Federal Aviation Administration managers and inspectors access to these records to enhance their oversight planning for production approval holders.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections1.11.2.3.3 Business Process Instruction "Perform Part or Assembly Removal," 1.11.2.4 Federal Aviation Administration Oversight of Boeing Production Processes, and 2.4.2.2 Ineffective Federal Aviation Administration Oversight. Information supporting (b)(1) can be found on pages 64-69 and 97-100; (b)(2) and (b)(3) are not applicable.

A-25-22

Convene an independent third-party panel to do conduct a comprehensive review of Boeing Commercial Airplanes' safety culture. The findings should be used to enhance the ongoing development of Boeing's regulatory safety management system (SMS) and the integration of its SMS into its broader quality management system.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.3.1, Quality Management System, 1.11.2.3.2 Voluntary Safety Management System, 1.12.2.4 Improvements to Quality Assurance and Safety Management Processes, 2.4.2.1 Boeing's Ineffective Corrective Actions, and 2.5 Need for Continued Development of Safety Management System. Information supporting (b)(1) can be found on pages 58–63, 73–75, 95–97, and 102–107; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 58–63, 73–75, 95–97, and 102–107.

A-25-23

Notify operators of the circumstances of the accident involving Alaska Airlines flight 1282, and encourage them to review their flight crew training programs and ensure that they include hands-on, aircraft-specific training and procedures for each type of oxygen system in the operator's fleet, to include establishing and maintaining communications when the oxygen masks are donned and removed while participating in realistic emergency procedures training scenarios.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.1 History of the Flight, 1.4.1 Captain, 1.4.2 First Officer, 1.11.1.1 Flight Crew Procedures and Training, and 2.6.1 Need for Hands-On Emergency Oxygen Mask Training. Information supporting (b)(1) can be found on pages 2–6, 8–10, 39–40, 78–79, and 107–110; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 2–6, 8–10, 39–40, 78–79, and 107–110.

A-25-24

Review and revise, as necessary, the design standards that apply to portable oxygen bottle design to ensure that they adequately address ease of use and quick donning in an emergency situation, including considerations for the effort needed to remove the mask from its packaging.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.1 History of the Flight, 1.4.3 Flight Attendants, 1.9 Survival

Aspects, 1.10.3.1 Passenger Service Units, 1.10.3.2 Portable Oxygen Bottles, 1.11.1.2 Cabin Crew Procedures and Training, and 2.6.2 Need for Portable Oxygen Bottle Design Standard Review. Information supporting (b)(1) can be found on pages 2–6, 10, 25–27, 36–38, 40–41, and 110–111; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 2–6, 10, 25–27, 36–38, 40–41, and 110–111.

A-25-25

Require operators of airplanes equipped with a cockpit voice recorder (CVR) to incorporate guidance into company standard operating procedures, emergency protocols, and postincident and postaccident checklists—applicable to both flight crew and non-flight crew personnel—detailing actions to preserve CVR recordings as soon as practical after completion of a flight with a reportable event.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.8.1 Cockpit Voice Recorder, 1.12.4.4 Procedures and Checklists for Cockpit Voice Recorder Circuit Breaker, and 2.6.2.1 Need for Effective Procedures for Preserving Cockpit Voice Recorder Data. Information supporting (b)(1) can be found on pages 24, 79, and 111–113; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 24, 79, and 111–113.

To The Boeing Company

A-25-26

Continue the certification process for the design enhancement for mid exit door plugs to ensure that, once the design enhancement is certified, all applicable newly manufactured airplanes are equipped with the enhancement.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.12.2.7 Ongoing Work on Mid Exit Door Plug Design Enhancement Certification and 2.3.2 Incomplete Closure of Left Mid Exit Door Plug. Information supporting (b)(1) can be found on pages 76 and 93; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 76 and 93.

A-25-27

Once the design enhancement for mid exit door (MED) plugs is certified, issue a service bulletin to address retrofitting in-service MED plug-equipped airplanes with the design enhancement.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.12.2.7 Ongoing Work on Mid Exit Door Plug Design

Enhancement Certification and 2.3.2 Incomplete Closure of Left Mid Exit Door Plug. Information supporting (b)(1) can be found on pages 76 and 93; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 76 and 93.

A-25-28

Apply your updated safety risk management process to current and future revisions to Business Process Instruction "Perform Part or Assembly Removal" to ensure that it provides clear and concise guidance for determining when a removal record is needed.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.3.3 Business Process Instruction "Perform Part or Assembly Removal" and 2.3.1.1 Complexity of Business Process Instruction "Perform Part or Assembly Removal." Information supporting (b)(1) can be found on pages 63-66 and 89-90; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 63-66 and 89-90.

A-25-29

Develop recurrent training on Business Process Instruction "Perform Part or Assembly Removal" for Boeing manufacturing personnel that emphasizes the importance of removal records for product safety, prepares personnel to consistently and correctly determine when a removal record is needed, and ensures that a removal record is generated when required.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.3.3 Business Process Instruction "Perform Part or Assembly Removal" and 2.3.1.1 Complexity of Process Instruction "Perform Part or Assembly Removal." Information supporting (b)(1) can be found on pages 63–66 and 89–90; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 63–66 and 89–90.

A-25-30

Develop a structured on-the-job training program that identifies and defines tasks necessary for manufacturing personnel to be considered fully qualified in their job series and includes a grading system for trainers and trainees to track progress and determine competence.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.2.1 Manufacturing Workforce Training, 1.12.2.3 Updates to Business Process Instructions, Installation Plans, and On-the-Job Training Related to Parts Removal, and 2.3.1.2 On-the-Job Training with Limited Exposure to

Nonroutine Tasks. Information supporting (b)(1) can be found on pages 51–65, 73, and 90–92; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 51–65, 73, and 90–92.

A-25-31

Document and archive the results of training provided and received as part of the program recommended in Safety Recommendation A-25-30 to support future data analysis.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.2.1 Manufacturing Workforce Training, 1.12.2.3 Updates to Business Process Instructions, Installation Plans, and On-the-Job Training Related to Parts Removal, and 2.3.1.2 On-the-Job Training with Limited Exposure to Nonroutine Tasks. Information supporting (b)(1) can be found on pages 51–65, 73, and 90–92; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 51–65, 73, and 90–92.

A-25-32

Revise your safety risk management process to ensure that it 1) identifies the root causes of manufacturing process compliance issues, like the persistent deficiencies with Business Process Instruction "Perform Part or Assembly Removal" and other production process inconsistencies identified in this investigation, and 2) evaluates the effectiveness of corrective actions.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.3.1 Quality Management System, 1.11.2.3.2 Voluntary Safety Management System, 1.12.2.4 Improvements to Quality Assurance and Safety Management Processes, 2.4.2.1 Boeing's Ineffective Corrective Actions, and 2.5 Need for Continued Development of Safety Management System. Information supporting (b)(1) can be found on pages 58–63, 73–75, 95–97, and 102–107; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 58–63, 73-75, 95–97, and 102–107.

A-25-33

As you integrate your quality management system and safety management system, develop a process that can identify escapes that result from human error, assess them using a system specifically designed to identify factors that contribute to such errors, and implement effective mitigation strategies.

Information that addresses the requirements of 49 *USC* 1117(b), as applicable, can be found in sections 1.11.2.3.1 Quality Management System, 1.11.2.3.2 Voluntary Safety Management System, 1.12.2.4 Improvements to Quality Assurance and Safety Management Processes, 2.4.2.1 Boeing's Ineffective Corrective Actions, and 2.5 Need for Continued Development of Safety Management System. Information supporting (b)(1) can be found on pages 8–63, 73–75, 95–97, and 102–107; (b)(2) is not applicable; and information supporting (b)(3) can be found on pages 8–63, 73–75, 95–97, and 102–107.

References

APA (American Psychological Association). 2018. *APA Dictionary of Psychology*, "Principle of Least Effort." Accessed April 8, 2025. https://dictionary.apa.org/principle-of-least-effort

Arvey, Richard D. and John M. Ivancevich. 1980. "Punishment in Organizations: A Review, Propositions, and Research Suggestions." *Academy of Management Review* 5 (1): 123–32.

Arvey, Richard D. and Allen P. Jones. 1985. "The Use of Discipline in Organizational Settings: A Framework for Future Research." In *Research in Organizational Behavior* vol. 7. Edited by Barry M. Staw and Larry L. Cummings: 367–408.

Ball, Gail A., Linda Klebe Trevino, and Henry P. Sims, Jr. 1994. "Just and Unjust Punishment: Influences on Subordinate Performance and Citizenship." Academy of Management Journal 37 (2): 299–322.

Barron, John M., Mark C. Berger, and Dan A. Black. 1997. *On-the-Job Training*. Upjohn Institute for Employment Research.

Boeing (The Boeing Company). n.d. "Strengthening Safety & Quality" Accessed July 3, 2025. https://www.boeing.com/strengthening-safety-and-quality#introduction

By, Rune T. 2005. "Organizational Change Management: A Critical Review." *Journal of Change Management* 5 (4): 369–80.

DOT IG (Department of Transportation, Office of Inspector General). 2024. *FAA's Oversight Processes for Identifying and Resolving Boeing Production Issues Are Not Effective*. DOT IG. AV2025002. October 9, 2024.

FAA (Federal Aviation Administration). 2014. "In-Flight Fires." Advisory Circular 120-80A. FAA. December 22, 2014.

—— 2022. "FAA Compliance and Enforcement Programs." FAA Order 2150.3C, CHG 10. FAA. November 14, 2022.

—— 2023. "Firefighting of General and High-Energy In-Flight Fires." Advisory Circular 120-28B. FAA. March 16, 2023.

—— 2024a. "Figure 5-88, Pilot Certificate Aircraft Type Designations – Airplane." FAA Order 8900.1, Volume 5, Chapter 2, Section 19. FAA. March 29, 2024.

—— 2024b. "FAA Continues to Hold Boeing Accountable for Implementing Safety and Production Quality Fixes." May 30, 2024. Retrieved from https://www.faa.gov

—— 2024c. "Safety Management System" home page, with a link for "SMS Explained." September 11, 2024. Retrieved from https://www.faa.gov/about/initiatives/sms Heinrich, Herbert W. 1930. "Industrial Accidents." *Monthly Labor Review* 30 (2): 83–92. Retrieved from https://www.jstor.org/stable/41860803

IAW (International Association of Machinists & Aerospace Workers). 2024. "IAM/Boeing Contract 2024." August 21, 2024. Retrieved from https://www.iam751.org

Indeed. 2025. "What are the Pros and Cons of Group Work?" June 6, 2025. Retrieved from https://www.indeed.com

Miller, Kelsey. 2020. "5 Critical Steps in the Change Management Process." Harvard Business School Online. Retrieved from https://online.hbs.edu/blog/post/change-management-process

Moran, John W. and Baird K. Brightman. 2001. "Leading Organizational Change." *Career Development International* 6 (2): 111–9.

NTSB (National Transportation Safety Board). 1995. *Flight Into Terrain During Missed Approach, USAir Flight 1016, DC-9-31, N954VJ, Charlotte/Douglas International Airport, Charlotte, North Carolina, July 2, 1994*. NTSB. AAR-95/03. April 4, 1995.

—— 2018. Extended Duration Cockpit Voice Recorders. NTSB. ASR-18-04. October 2, 2018.

—— 2021. *Preventing Turbulence-Related Injuries in Air Carrier Operations Conducted Under Title 14* Code of Federal Regulations *Part 121*. NTSB. SS-21/01. August 10, 2021.

—— 2024. *Runway Incursion and Overflight, Southwest Airlines Flight 708, Boeing 737-700, N7827A, and Federal Express Flight 1432, Boeing 767-300, N297FE, Austin, Texas, February 4, 2023*. NTSB. AIR-24-02. June 6, 2024.

Reason, James T. 1990. *Human Error*. Cambridge University Press.

—— 1997. *Managing the Risks of Organizational Accidents*. Ashgate.

SKYbrary. n.d. "Commercial Pressures." Accessed April 8, 2025. https://skybrary.aero/articles/commercial-pressures

—— n.d. "The Human Factors Dirty Dozen." Accessed April 8, 2025. https://skybrary.aero/articles/human-factors-dirty-dozen

—— n.d. "Just Culture." Accessed June 3, 2025. https://skybrary.aero/articles/just-culture

Spirit (Spirit AeroSystems). n.d. "Home Page." Accessed April 8, 2025. https://www.spiritaerosystems.com

Vasanthi, Sree and S. Rabiyathul Basariya. 2019. "Pros and Cons of On the Job Training versus Off the Job Training." *International Journal of Scientific & Technology Research* 8 (10): 671–4.

Wood, Susanne. 2004. "Fully On-the-Job Training: Experiences and Steps Ahead." Research report, National Centre for Vocational Education Research, under license from Australian National Training Authority.

Wright, Patricia. 1981. "'The Instructions Clearly State…' Can't People Read?" *Applied Ergonomics* 12 (3): 131–41.

The NTSB is an independent federal agency charged by Congress with investigating every civil aviation accident in the United States and significant events in the other modes of transportation—railroad, transit, highway, marine, pipeline, and commercial space. We determine the probable causes of the accidents and events we investigate and issue safety recommendations aimed at preventing future occurrences. In addition, we conduct transportation safety research studies and offer information and other assistance to family members and survivors for each accident or event we investigate. We also serve as the appellate authority for enforcement actions involving aviation and mariner certificates issued by the Federal Aviation Administration (FAA) and US Coast Guard, and we adjudicate appeals of civil penalty actions taken by the FAA.

The NTSB does not assign fault or blame for an accident or incident; rather, as specified by NTSB regulation, "accident/incident investigations are fact-finding proceedings with no formal issues and no adverse parties … and are not conducted for the purpose of determining the rights or liabilities of any person" (Title 49 *Code of Federal Regulations* section 831.4). Assignment of fault or legal liability is not relevant to the NTSB's statutory mission to improve transportation safety by investigating accidents and incidents and issuing safety recommendations. In addition, statutory language prohibits the admission into evidence or use of any part of an NTSB report related to an accident in a civil action for damages resulting from a matter mentioned in the report (Title 49 *United States Code* section 1154(b)).

For more detailed background information on this report, visit the NTSB Case Analysis and Reporting Online (CAROL) website and search for NTSB accident ID DCA24MA063. Recent publications are available in their entirety on the NTSB website. Other information about available publications also may be obtained from the website or by contacting –

National Transportation Safety Board
Records Management Division, CIO-40
490 L'Enfant Plaza, SW
Washington, DC 20594
(800) 877-6799 or (202) 314-6551

Copies of NTSB publications may be downloaded at no cost from the National Technical Information Service, at the National Technical Reports Library search page, using product number PB2025-100108. For additional assistance, contact–

National Technical Information Service
5301 Shawnee Rd.
Alexandria, VA 22312
(800) 553-6847 or (703) 605-6000
NTIS website