National Transportation Safety Board

Washington, D.C. 20594

Accident Number:	DCA11MA039
Operator/Flight Number:	Southwest Airlines, Flight 812
Aircraft and Registration:	Boeing 737-3H4, N632SW
Location:	Yuma, Arizona
Date:	April 1, 2011
Adopted:	September 24, 2013

HISTORY OF FLIGHT

On April 1, 2011, about 1558 mountain standard time (MST),[1] a Boeing 737-3H4, N632SW, operating as Southwest Airlines flight 812 experienced a rapid decompression while climbing through flight level 340. The flight crew conducted an emergency descent and diverted to Yuma International Airport (NYL), Yuma, Arizona. Of the 5 crewmembers and 117 passengers on board, one crewmember and one nonrevenue off-duty airline employee passenger sustained minor injuries. The airplane sustained substantial damage; postaccident inspection revealed that a section of fuselage skin about 60 inches long by 8 inches wide had fractured and flapped open on the upper left side above the wing. The flight was conducted under the provisions of 14 *Code of Federal Regulations* (CFR) Part 121 as a regularly scheduled domestic passenger flight from Phoenix Sky Harbor International Airport, Phoenix, Arizona, to Sacramento International Airport, Sacramento, California.

According to the flight crew and recorded data, the takeoff and initial climb were normal. At 1558:05, an unidentified sound was recorded on the cockpit area microphone. About 2 seconds later, the captain announced that the airplane had lost cabin pressurization and called for oxygen masks on; sounds consistent with increased wind noise were heard on the cockpit voice recording. The captain declared an emergency with air traffic control and requested a lower altitude. The air traffic controller provided lower altitude clearances, and the flight crew descended the airplane to 11,000 feet within 5 minutes. Cabin oxygen masks deployed, and about 1605, the cabin crew began relaying condition reports to the flight crew describing a 2-foot hole in the fuselage and one broken-nose injury of a cabin crewmember. The airplane was cleared for further descent to 9,000 feet, and the captain requested radar vectors to the nearest suitable airport (NYL). The airplane landed about 1629 on runway 21R at NYL without further incident. The passengers deplaned via airstairs.

[1] Unless otherwise noted, all times in this brief are MST based on a 24-hour clock.

INJURIES TO PERSONS

One cabin crewmember (flight attendant A) and one nonrevenue off-duty airline employee passenger sustained minor injuries. Flight attendant A lost consciousness while attempting to make an interphone call or P/A announcement to passengers, struck the forward partition, and sustained a laceration and fracture of his nose. The employee passenger lost consciousness and fell while attempting to assist flight attendant A. He sustained a laceration above his eye during the fall. Both flight attendant A and the employee passenger regained consciousness as the airplane descended.

DAMAGE TO AIRCRAFT

Postaccident inspection of the airplane revealed that a section of fuselage skin about 60 inches long by 8 inches wide had fractured and flapped open on the upper left side above the wing (see figure 1). The damaged section of fuselage side skin was bounded by body station[2] (BS) 663 and BS 727 in the fore-aft direction and stringer[3] (S)-4L and S-5L in the circumferential direction (see figure 2). S-4L is the location of a lap joint with three rivet rows. The entire section of skin remained attached along the lower edge and was deformed outward. There were some abrasion marks on the fuselage skin below the forward edge of the hole that matched the shape of the forward edge of the attached section. The fracture along the upper edge was through the lower rivet row of the lap joint. The forward edge was fractured about 1/2 inch aft of the edge of the bonded doubler at BS 663. The aft edge was fractured along the forward rivet row of the BS 727 butt joint. There was some deformation to the intercostal installed between the BS 663 and BS 685 frames. There was no visible damage to the surrounding frames, stringers, and stringer clips. Some insulation was missing from the location around the hole. During the postaccident skin repair, two cracked stringer clips were found along S-4L (at BS 685 and at BS 706).

[2] Body station numbers represent the number of inches measured along the length of the airplane from a set datum point at the forward end of the airplane.

[3] Stringers are numbered from stringer 1 at the top center of the fuselage sequentially down the left and right sides of the airplane as viewed from the tail of the airplane looking forward.

Figure 1. Photograph of N632SW with the hole in upper left fuselage.

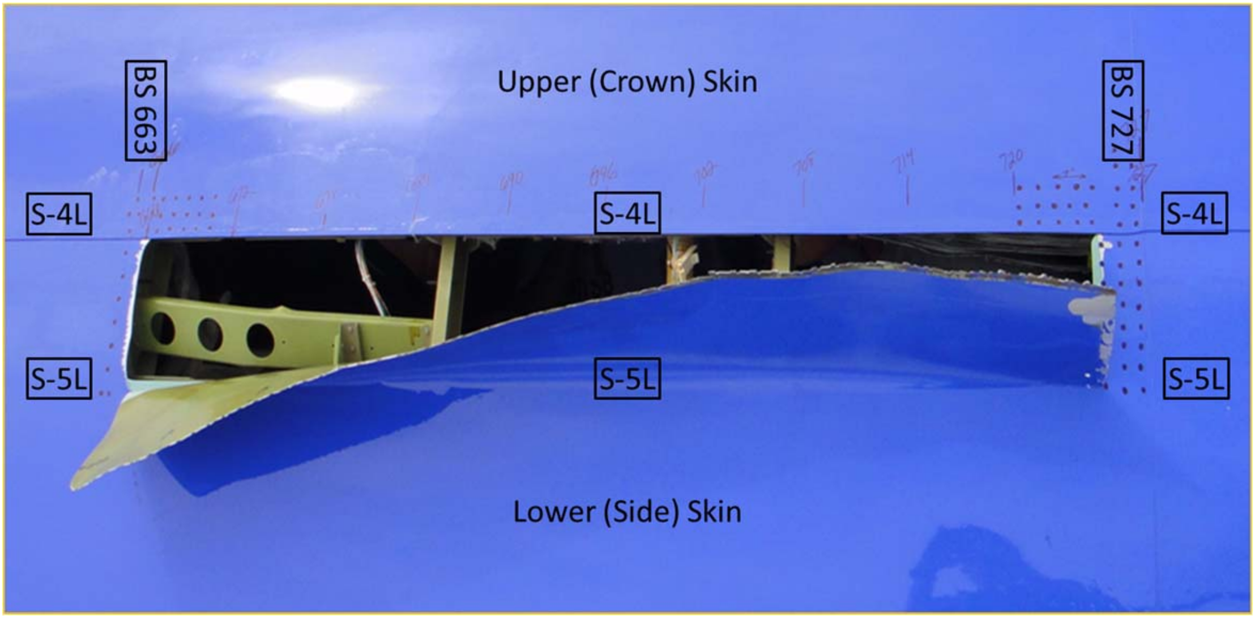

Figure 2. Close-up photograph of hole in fuselage side skin on N632SW.

OTHER DAMAGE

None.

PERSONNEL INFORMATION

The captain, age 56, held an airline transport pilot certificate with type ratings in the Boeing 737, 757, and 767. He held a valid Federal Aviation Administration (FAA) first-class medical certificate with a requirement that he wear glasses for near vision. He reported 17,000 hours total flight time in the Boeing 737. The first officer, age 51, held an airline transport pilot certificate with a type rating in the Boeing 737. He held a valid FAA first-class medical certificate with no restrictions. He reported 6,350 hours total flight time in the Boeing 737.

The cabin crew consisted of three flight attendants. Flight attendant A, age 49, held a valid flight attendant certificate and had 12 years of experience on the Boeing 737 at Southwest Airlines. Flight attendant B, age 64, held a valid flight attendant certificate and had 14 years of experience on the Boeing 737 at Southwest Airlines. Flight attendant C, age 32, held a valid flight attendant certificate and had 10 years of experience on the Boeing 737 at Southwest Airlines.

AIRCRAFT INFORMATION

The accident airplane, a Boeing 737-3H4, N632SW (serial number 27707 and line number 2799), was manufactured on May 22, 1996, and delivered new to Southwest Airlines on June 13, 1996. At the time of the accident, the airplane had 48,748 total hours with 39,786 total cycles. The airplane was powered by two General Electric/SNECMA CFM-56-3B1 engines.

The accident airplane fuselage was manufactured by the Boeing Company at its facility in Wichita, Kansas, and left Wichita on April 1, 1996. The fuselage sections were shipped in two pieces by rail to the final assembly facility in Renton, Washington, and were delivered on April 8, 1996. At the time of manufacture, the fuselage sections were drilled and riveted manually at the lap splices.

The Wichita facility was divested in 2005 and is currently known as Spirit AeroSystems. Spirit AeroSystems was able to provide some documentation regarding the generic work planning documents that the mechanics used for building the fuselage sections of the airplane. However, the fuselage section build paperwork for the accident airplane was not available at Spirit AeroSystems, nor was it required to be retained. (Although not required by the FAA, at the time, the Boeing Operations and Inspections record policy was to keep the documention for the current year plus 6 years.)

The Boeing Renton facility joined the forward and aft fuselage sections at BS 727. Some of the drilling and riveting around the BS 727 joint was intentionally left incomplete by Boeing Wichita to allow for ease of production that Renton would finish later. The installation of the accident airplane crown skin panel above the hole was a split installation where the work was partially performed at the Wichita site and finished at the Renton site. The actual completed job records for the accident airplane were no longer available at Renton and were not required to be retained. Any configuration changes that would have occurred on the factory floor should have been documented by a rejection tag. None of the Renton rejection tags associated with the accident airplane line number showed any changes to the accident skin panel. The Wichita rejection tags were not available for review and were not required to be retained. Further, the Southwest Airlines maintenance records for the accident airplane were examined and contained no evidence of any major repairs or alterations performed on the accident crown skin or side skin panels.

At the time of manufacture, the Boeing quality assurance (QA) processes for in-factory skin panel re-work and factory production skin panel installation were similar. Inspections would be conducted on holes after drilling and after separating the skins for de-burring. A QA stamp would be required for "ok to seal" before fastener installation, and another QA acceptance would be required of the installed fasteners and other components. Boeing noted that the QA process was the same at the time of the accident as at the time of manufacture, but the current production variant of 737 (next generation, or "NG," as opposed to the accident airplane, a -300 variant, part of the "classic" series) has a different design at the lap joint that has an improved fatigue life; more modern manufacturing techniques are used, such as 3D computer design, machine-driven rivets, and laser alignment.

FLIGHT RECORDERS

The solid-state cockpit voice recorder (CVR) was a Honeywell 6022 SSCVR 120 that recorded 2 hours of digital cockpit audio. The audio information was extracted from the CVR normally, without difficulty. The quality of the audio was characterized as good to excellent. No CVR group was convened, and a summary was prepared by the National Transportation Safety Board (NTSB) recorders lab.

The solid-state flight data recorder (FDR), a Honeywell SSFDR, model 980-4700, records a minimum of 25 hours of airplane flight information in a digital format. The FDR was in good condition, and the data were extracted normally from the FDR.

The times used in this report are expressed as MST. Timing was established by correlating the CVR events to common events on the FDR; time was also recorded as a parameter on the FDR in this airplane. This resulted in a fixed relationship between FDR subframe reference number, MST, and CVR elapsed time.

SURVIVAL ASPECTS

All of the passenger oxygen mask doors were found open, and all of the passenger oxygen generation cylinders had heat indication tape that indicated activation. The forward and aft flight attendant oxygen generation cylinders had heat indication tape that indicated activation. The forward flight attendant station had no oxygen masks present. There was one oxygen mask on the floor at row 1-DEF that had blood on it. The aft flight attendant station had two oxygen masks present.

After the decompression, flight attendant A stated that there were two "high priority" tasks: ensuring that the passengers put on their oxygen masks and establishing communication with the flight crew. He recalled that he went to the forward galley and was about to either call the captain on the interphone or make a P/A announcement to the passengers when he lost consciousness, fell, and struck his nose on the forward partition. Although Southwest Airlines training materials indicated that the first action a flight attendant should take after a decompression was to take oxygen from the nearest mask immediately, he stated that he thought he "could get a lot more done" before getting his oxygen mask on.

Southwest Airlines provided its flight attendants with initial and recurrent training as well as information in the flight attendant manual regarding decompressions. All of the materials reviewed were consistent in their guidance to flight attendants. The first two steps to be taken following a decompression were to (1) take oxygen from the nearest mask immediately and (2) "secure yourself." Only when the airplane had reached a safe walking attitude or after contact with the flight crew had been made were the flight attendants trained to attempt a P/A announcement to passengers. Further, Southwest Airlines training materials indicated that "at any cruise altitude, pressurization maintains cabin altitude of 6,000-8,000 feet. If pressure is lost, prompt action is required to maintain occupant consciousness. The time of useful consciousness ranges from as much as 90 seconds (in a mechanical failure) at 30,000 feet, to as little as six seconds (in a rapid decompression) at 41,000 feet."[4] Flight attendant A received his initial training in September 1998 and his last recurrent training in September 2010.

TESTS AND RESEARCH

After the accident, all of the airplane's interior components and insulation were removed, allowing examination of the interior surface of the fuselage skins. The visible markings on the skin panels[5] surrounding the crown skin panel (BS 540 to BS 727, S-4L to S-4R) immediately above the fractured skin panel were documented. Typically, a skin panel should have two markings: one for the manufacture of the skin panel itself and one for the manufacture of the built-up panel assembly. Additionally, the built-up panel assembly should have a marking to indicate that the assembly had been approved by the QA process. Figure 3 shows the markings on the accident airplane. The three-panel crown assembly from S-10L and S-10R that included the fracture had QA stamps dated February 16, 1996, with the exception of the grey panel in figure 2. The panel assemblies aft of the accident crown panel had QA stamps dated February 27, 1996. One of the three panel assemblies forward of the accident crown panel had a QA stamp dated February 23, 1996, while the other two markings were obstructed. The accident crown skin panel above the fracture and coincident with the lap joint where the fracture occurred only had a stamp for the skin panel manufacture and was dated March 5, 1996.

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[4] This information is based on FAA Advisory Circular (AC) 61-107, "Operations of Aircraft at Altitudes Above 25,000 Feet MSL [mean sea level] and/or MACH Numbers…Greater Than .75," dated January 23, 1991.

[5] The skin panel is a flat piece of aluminum with a doubler bonded to it. The stringers, frames, and other internal structures are installed, creating the built-up panel assembly.

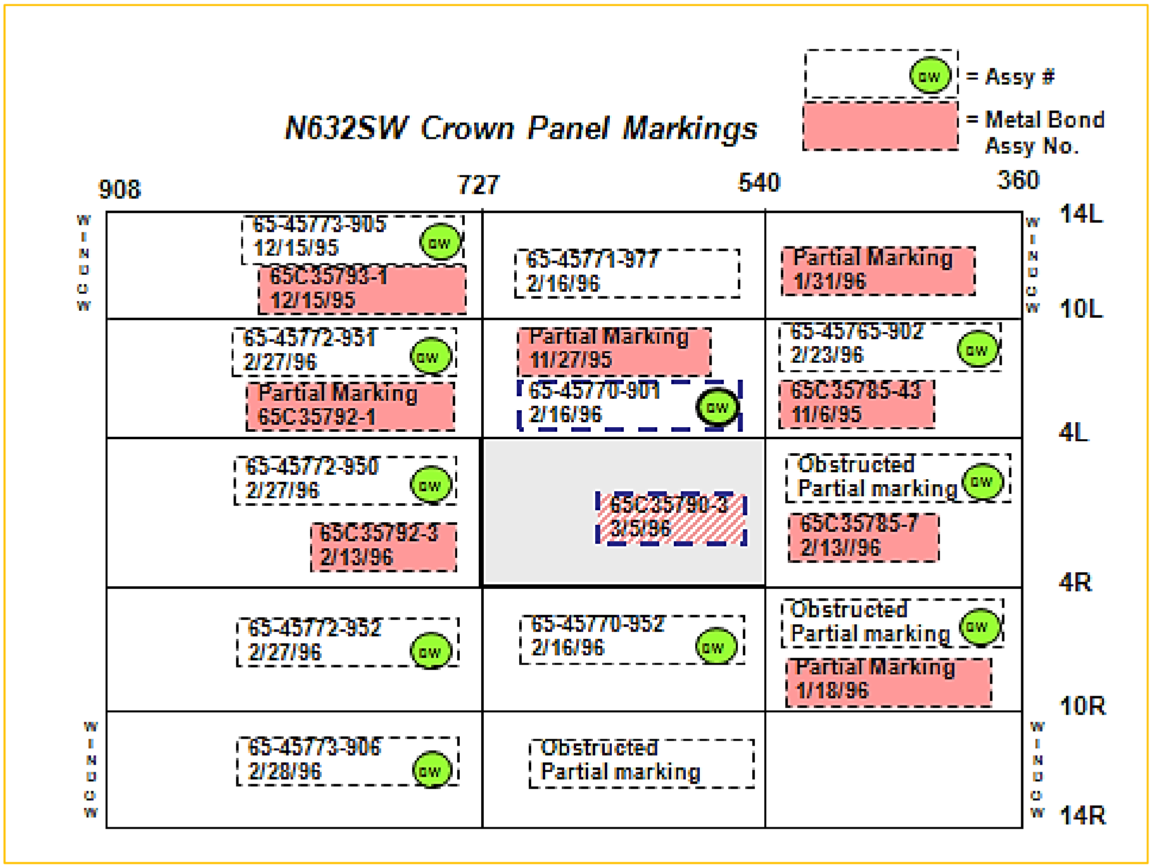

Figure 3. Documented markings on the accident airplane skin panels.

Note: The pink shaded boxes represent the skin panel manufacturing information (metal bond assembly number), the unshaded boxes represent the built-up panel assembly information (assembly number), the green circles represent the QA stamp for Boeing Wichita, and the grey shaded box in the center represents the crown skin panel above the fractured skin panel.

The area of the accident airplane skin panels containing the hole was excised from the airplane and sent to the NTSB materials laboratory for detailed examination, which revealed that the longitudinal fracture extended through the lower skin portion of the lap joint at S-4L. The fracture extended between BS 666 and BS 725 and through the lower row of rivets of the lap joint, intersecting 58 consecutive rivet holes at approximately 1-inch intervals. (A cross section of the lap joint on the accident airplane is shown in figure 4.)

During manufacture, the bond assembly for a skin panel is created by hot bonding an internal doubler to the upper skin. The inner surfaces of the upper and lower skin panels are anodized and primed. The outer surface of the lower skin panel is unfinished clad aluminum in the area where it will fay with the upper skin internal doubler. During installation, the upper skin and internal doubler assembly overlaps the lower skin assembly, forming a lap joint. BMS5-95 polysulfide sealant is applied between the doubler bonded to the upper skin and the lower skin faying (adjoining) surfaces. The joint is then fastened with three rows of rivets. The stringer is attached along the middle rivet row. The rivet holes were sequentially numbered from 1 to 112 on the accident skin panel for identification purposes. The airplane was delivered with the outer top surface of the fuselage painted tan (the original Southwest Airlines paint scheme). In January 2011, blue paint was applied to the outer top portion of the airplane.

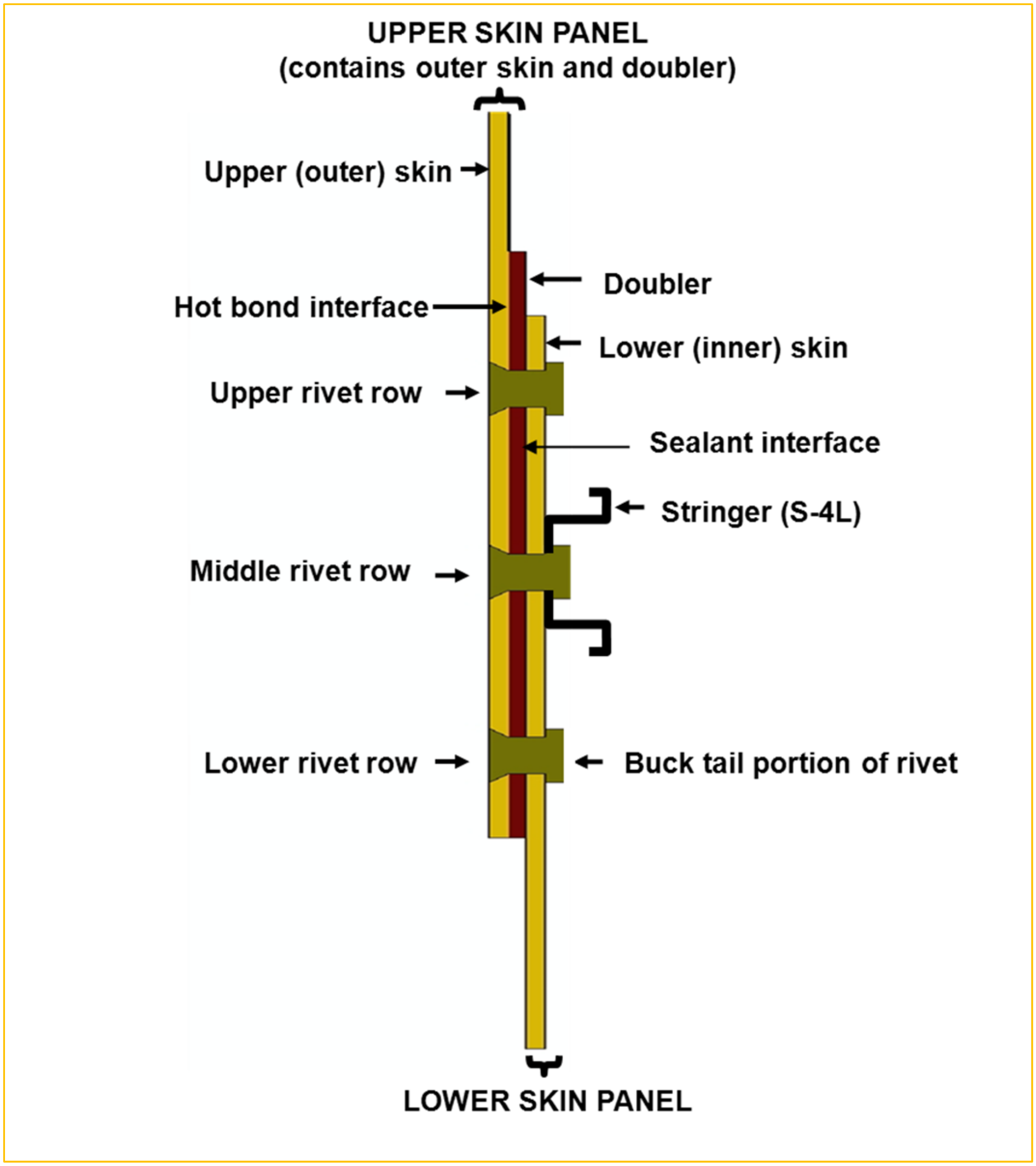

Figure 4. Diagram of a Boeing 737 lap joint in the fracture area (not to scale).

The inner surface of the doubler was exposed when the lower skin fractured along the lower rivet row. The exposed inner surface was coated with a dark gray deposit consistent with BMS5-95 sealant. Evidence of blue exterior paint and green primer was found on the surface of the sealant. The exposed surface at the lower edge of the doubler and in the areas that corresponded with the length of the longitudinal fracture contained minor rubbing (fretting) damage. The areas within the fretting damage area showed evidence of bare metal. The mating surface (outer surface of the lower skin) showed a mirror image of the sealant, paint, and bare metal features that were found on the exposed face of the doubler. The fretting damage areas were consistent with contact and relative motion between the lower edge of the doubler and the lower skin.

Microscopic examination of the longitudinal portion of the fracture surfaces revealed thumbnail fracture features consistent with fatigue cracking that originated from 54 out of 58 rivet holes. The fatigue cracks emanated from the outer surface of the lower skin. This surface is not visible from the interior or exterior of the airplane. In nine adjoining rivet holes (81 through 89), fatigue cracking occurred through 100% of the skin thickness. The depth of each fatigue crack varied along its length. The two longest fatigue cracks were found on the forward and aft side of rivet hole 85. The crack on the forward side of the rivet hole measured 0.55 inch, and the crack on the aft side measured 0.60 inch. The fatigue cracks propagated forward and aft with respect to each rivet hole. Figure 5 shows a drawing of the fuselage skin in the area of the fracture. As the distance from rivet hole 85 was increased, the length of a fatigue crack on each side of a rivet hole for each successive rivet hole decreased. The fracture face in the areas located outside of the fatigue crack regions showed rough texture features consistent with overstress separation. The remaining 4 of the 58 rivet holes (69, 71, 97, and 98) contained no evidence of fatigue cracking. The fracture intersected two tear straps[6] at BS 685 and BS 706. The face of the fracture for the tear straps contained no evidence of fatigue cracking.

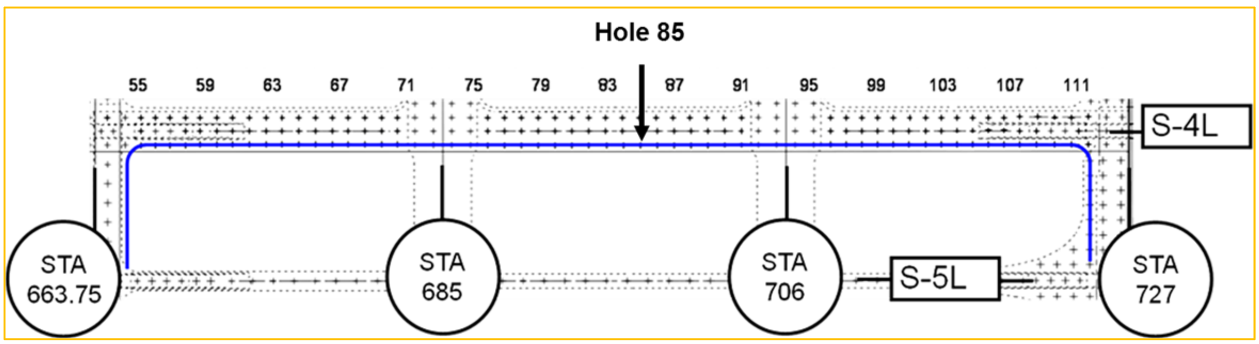

Figure 5. Drawing of the lap joint in the area of fracture (blue line represents the fracture).

Examination of the rivets in the fracture area revealed that 10 of the 58 lower-row rivets were oversized, while the upper-row rivets were standard sized. Numerous bucked tails on the lower-row rivets exhibited a finish that was different than rivets elsewhere on the panel, ranging anywhere from exposed bare aluminum to partially covered with primer to fully covered with primer coating. Additionally, many rivets in the lap joint were under driven, and areas around the driven heads exhibited curled metal consistent with metal burrs. Microscopic examination of the disassembled rivets revealed the diameter of the shank portion in the area adjacent to the bucked tail portion for a majority of the rivets was larger (expanded) compared to the diameter of the shank. The expanded diameter portion in the shank coincided with the thickness and larger hole in the lower skin. Figure 6 shows the side profile view of rivet 85 with its corresponding rivet hole. At the inner surface of the lap joint, the rivet holes in the upper and lower skins were found to be slightly offset relative to each other, and many of the rivet holes on the lower skin were not

[6] Tear straps are fail-safe elements of the skin assembly. They are vertical straps created by the retained portions of the hot-bonded doubler after chemical milling.

circular but slightly oval. Many of the rivet holes appeared similar to a figure 8 or a double-drilled hole. The fracture (fatigue cracks) intersected the lower portion of a majority of the lower-row rivet holes. The corresponding area located at the underside of the expanded portion of the rivets also showed fretting damage consistent with the underside of the expanded portion of the shank rubbing against the doubler. The bore of many rivet holes contained deposits of dark gray material consistent with BMS5-95 sealant.

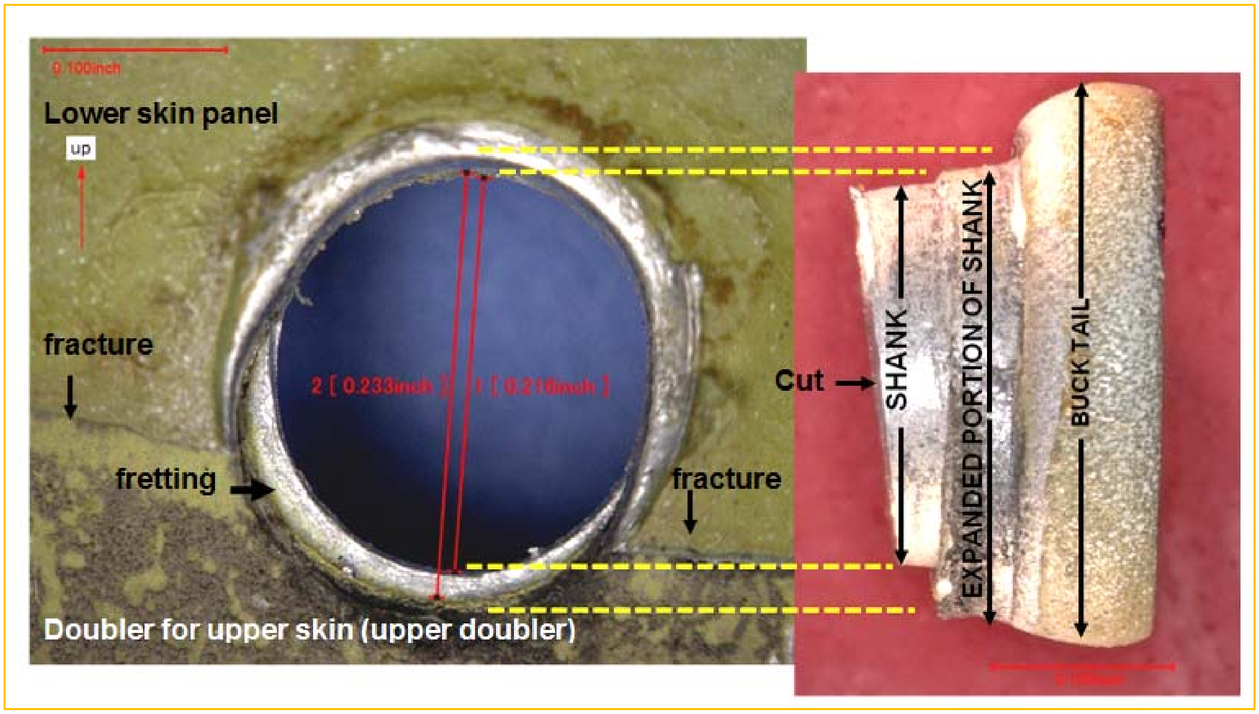

Figure 6. Rivet hole 85L when viewed from inner face of the skin panel (left side) and side view of corresponding rivet that was removed from the rivet hole (right side).

The material composition, hardness, electrical conductivity, and thickness of the upper skin, lower skin, and doubler were examined along with several rivet samples. All of the materials examined corresponded to their respective Boeing specifications.

The NTSB materials laboratory performed a fatigue striation count on the longest fatigue crack located on the aft side of rivet hole 85. Boeing also performed fatigue striation counts on several other smaller fatigue crack areas. The data for all of the cracks examined showed reasonable agreement in the crack growth rates. The calculated total number of cycles for the longest fatigue crack located on the aft side of rivet hole 85 was 38,261 cycles. (The airplane had 39,786 total cycles at the time of the accident.)

ORGANIZATIONAL AND MANAGEMENT INFORMATION

Southwest Airlines was certificated as a 49 CFR Part 121 air carrier and was headquartered in Dallas, Texas. As of March 31, 2011, the company's fleet consisted of 553 Boeing 737 airplanes, including 171 Boeing 737-300s, 25 Boeing 737-500s, and 357 Boeing 737-700s. The accident airplane was owned and operated by Southwest Airlines for common carrier passenger operations.

ADDITIONAL INFORMATION

Time of Useful Consciousness

On December 20, 2000, as a result of an October 25, 1999, LearJet 35 decompression accident near Aberdeen, South Dakota,[7] the NTSB issued Safety Recommendation A-00-109, which asked the FAA to do the following:

> (1) Revise existing guidance and information about high-altitude operations to accurately reflect the time of useful consciousness and rate of performance degradation following decompression and to highlight the effect of hypoxia on an individual's ability to perform complex tasks in a changing environment and (2) incorporate this revised information into both the required general emergency training conducted under 14 [CFR] Parts 121 and 135 and training and flight manuals provided to all pilots operating pressurized aircraft.

In response, the FAA issued AC 61-107A in 2003; however, on June 24, 2004, the NTSB expressed its concern that the time of useful consciousness may be a much shorter period of time than was indicated in the AC. The NTSB indicated that the information provided in AC 61-107A is misleading and needs to be revised to emphasize that time is of the essence in a depressurization. On December 27, 2005, the NTSB again expressed its concern that the time of useful consciousness data do not represent actual pilot performance under realistic decompression conditions. The NTSB evaluated AC 61-107B, which was issued on March 29, 2013, and determined that the revisions made to the AC did not address the NTSB's concerns about the time of useful consciousness. As a result, Safety Recommendation A-00-109 was classified "Closed—Unacceptable Action" on September 18, 2013.

Postaccident Boeing and FAA Actions

On April 4, 2011, Boeing released Alert Service Bulletin (ASB) 737-53A1319 instructing operators to inspect the lower row of fasteners at S-4L and S-4R, from BS 360 to BS 908, for cracking in the lower skin of the lap joint. The ASB was effective for all Boeing 737 airplanes with line numbers 2553 through 3132 and called for an external dual frequency eddy current (DFEC) inspection[8] of the lap joint. As an alternative, the operator could perform an internal eddy current inspection of the lower lap joint fastener row. The ASB recommended that the initial inspection occur before an airplane had 30,000 total flight cycles or within 20 days of the original issue date of the ASB, whichever occurred later. For airplanes with 30,000 to 34,999 total flight cycles, the ASB recommended compliance within 20 days of the original issue date, and for airplanes that had 35,000 total flight cycles or more, the ASB recommended compliance

[7] More information about this accident, NTSB case number DCA00MA005, can be found at http://www.ntsb.gov/aviationquery/index.aspx.

[8] An external DFEC inspection uses electromagnetic induction principle to detect cracks in areas where the cracks would not be visible due to the presence of other structure (such as under the upper skin).

within 5 days of the original issue date. The inspections were recommended to be repeated at intervals not to exceed 500 flight cycles.[9]

On April 5, 2011, the FAA issued emergency airworthiness directive (AD) 2011-01-15 requiring inspections of the S-4L and S-4R lap joints per the details presented in the original Boeing ASB. The AD was effective immediately. As a result of the AD inspections, several other Boeing 737 airplanes were found with one to five small fatigue cracks at various locations along the lower rivet row at S-4. None of the airplanes had the extensive fatigue cracking or double-drilled (figure 8) holes evident on the accident airplane.

Boeing’s record retention requirements for manufacturing records related to build and assembly processes were for the current production year plus the previous 6 years at the time the accident airplane was in production. A search for completed manufacturing records did not return any results, as record storage requirements indicated that any records older than 7 years should be destroyed.

On April 16, 2011, the FAA promulgated the first regulatory requirement for the retention of manufacturing records, 14 CFR 21.137, which required the retention of quality control records. The rule states, in part, that a production approval holder must retain these records for at least 5 years “for the products and articles manufactured under the approval” and at least 10 years for critical components. Before 14 CFR 21.137 was issued, there were no regulatory requirements for the retention of manufacturing records, just a policy agreed upon between the manufacturer and the FAA. In April 2011, Boeing increased its retention requirements for all manufacturing records to 10 years.

[9] On April 8, 2011, Boeing released Revision 1 to the ASB that clarified some of the figures but did not change the details of the inspection.

ANALYSIS

There were no relevant anomalies during the preflight check, taxi, and initial portions of the accident flight. No crew actions or inactions affected the separation of the portion of crown skin from the fuselage. The NTSB concludes that flight crew response to the decompression was timely and effective.

Time of Useful Consciousness

Flight attendant A attempted to make either an interphone call or a P/A announcement to passengers before obtaining oxygen, leading to his loss of consciousness and fractured nose. His decision to make the call or P/A announcement before obtaining oxygen was inconsistent with Southwest Airlines training materials, which clearly indicated that flight attendants should first obtain oxygen and secure themselves in the event of a decompression. In a postaccident interview, the flight attendant stated that he thought he "could get a lot more done" before getting his oxygen mask on. The NTSB concludes that flight attendant A attempted to perform actions before obtaining oxygen and lost consciousness, likely due to an incorrect assessment of his time of useful consciousness.

Structural and Manufacturing Aspects of the Accident Airplane

Detailed laboratory examination of the removed skin piece revealed that the fracture occurred along the lower rivet row and intersected 58 rivet holes (numbered 55 through 112). The fatigue fracture area was not visible from either the exterior or the interior of the airplane. The two longest fatigue cracks were almost twice as long as the next longest and were located forward and aft of rivet hole 85. These cracks and others in the area had propagated entirely through the skin thickness. The NTSB concludes that fatigue cracking initiated at rivet hole 85 located at BS 697. The material properties for the skins, doubler, and rivets were all checked and satisfied the Boeing specification requirements. Thus, the NTSB concludes that material properties did not contribute to the skin fatigue crack.

The mating outer surface of the lower skin and the inner surface of the upper doubler had evidence of green primer and blue exterior paint on the surface of the sealant, indicating a breakdown in the lap joint sealant before the blue paint was applied. There was also rubbing (fretting) damage and areas of exposed bare metal adjacent to the areas where the fatigue cracking was located, which was caused by the relative movement of the lower skin and doubler. Thus, the fatigue cracking and breakdown in the lap joint had been present for a prolonged period of time.

The NTSB materials laboratory and Boeing both performed fatigue striation counts on several areas of the fatigue cracking. The data for all of the cracks examined showed reasonable agreement in the crack growth rates. The calculated total number of cycles for the longest fatigue crack located on the aft side of rivet hole 85 was 38,261 cycles, which was within about 1,500 cycles of the total cycles on the airplane. The NTSB concludes that the fatigue cracking at rivet hole 85 began approximately when the airplane entered service.

Examination of the rivets in the fracture area revealed numerous anomalies, including oversized rivets, variations in finish, under-driven conditions, expanded shank areas, and crank-shafting. Most of the lower-row holes in the lower skin had discrepancies including ovalized holes, double-drilled holes, gaps between the buck tail and the hole, sealant in the rivet hole, and burrs protruding from under the buck tail. Examination of the lap joint before it was separated revealed that almost all of the lower-row holes in the lower skin were offset from the holes in the upper skin and attached doubler. The hole quality in the crown and left side skin panels was not in accordance with Boeing specifications or standard manufacturing practices and showed a lack of attention to detail and extremely poor manufacturing technique.

The fuselage barrel section that included the fracture area left Boeing Wichita on April 1, 1996, and was delivered to the factory in Renton on April 8, 1996. Southwest Airlines had not replaced the crown skin or upper skin panel in the fracture area. All of the skin panels surrounding the crown skin panel had markings consistent with the drawings, had an inspection stamp from Boeing Wichita, and were dated January 18, 1996, through February 27, 1996. The crown skin panel from BS 540 to BS 727 only had a chemical conversion coating stamp, no inspection stamp, and was dated March 5, 1996. There were no records or associated rejection tags documenting replacement of the crown skin panel at either Boeing Wichita (currently Spirit Aerosystems) or Boeing Renton. The NTSB concludes that the panel markings indicate that the crown skin panel from BS 540 to BS 727 was replaced during manufacture; however, it could not be determined if this occurred at the Boeing Wichita or Renton facilities. The Boeing QA process for an in-factory re-work followed the same steps as factory production, requiring multiple inspections and approvals.

Because the accident occurred beyond the manufacturing records retention period, the investigation could not determine why the crown skin panel was replaced or how the poor repair was not identified in the QA process. However, evidence indicates that during drilling of the S-4L lap joint, the crown skin panel and the upper left fuselage panel were misaligned, so most of the lower rivet row holes were misdrilled. Many of the installed rivets did not completely fill the holes in the lower skin panel, which significantly reduced the fatigue life of the panel. The pressurization loads on the fuselage skin initiated fatigue cracking at rivet hole 85 almost immediately after manufacture. Fatigue cracking subsequently initiated in adjacent rivets along the skin panel and grew over time with each application of pressurization loads. The NTSB concludes that on the accident flight, the cumulative amount of fatigue cracking reached a critical length, and the panel’s residual strength was not sufficient to carry the loads, which resulted in the hole flapping open and rapid depressurization of the airplane.

The fatigue cracking in the lower rivet row can be characterized as multiple site damage where small individual fatigue cracks grow slowly over time to a point where they link up, causing failure. The FAA issued AD 2011-01-15 to require compliance with Boeing ASB 737-53A1319 to inspect the S-4L and S-4R lap joints on all Boeing 737 classic airplanes from line numbers 2553 to 3132. There were no similar findings of multiple site damage in the lap joints of the Boeing 737 classic airplanes as was found on the accident airplane; thus, the NTSB concludes that it is unlikely that there was a systemic QA error at the Boeing facilities in Wichita or Renton at the time of manufacture.

PROBABLE CAUSE

The National Transportation Safety Board determines that the probable cause of this accident was the improper installation of the fuselage crown skin panel at the S-4L lap joint during the manufacturing process, which resulted in multiple site damage fatigue cracking and eventual failure of the lower skin panel. Contributing to the injuries was flight attendant A's incorrect assessment of his time of useful consciousness, which led to his failure to follow procedures requiring immediate donning of an oxygen mask when cabin pressure is lost.

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