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

STRUCTURES GROUP CHAIRMAN'S FACTUAL REPORT

March 22, 2019

A. ACCIDENT: ERA18FA120

Operator:	Embry-Riddle Aeronautical University
Location:	Daytona Beach, Florida
Date:	April 4, 2018
Time:	0953 EDT
Aircraft:	Piper PA-28R-201 Arrow III
Registration:	N106ER

B. STRUCTURES GROUP

Chairman:	Clinton R. Crookshanks National Transportation Safety Board Denver, Colorado
Member:	Dan McCully Federal Aviation Administration College Park, Georgia
Member:	Damian Galbraith Piper Aircraft, Inc. Vero Beach, Florida
Member:	Michael Gordon Piper Aircraft, Inc. Vero Beach, Florida
Member:	Thomas Bruno Embry-Riddle Aeronautical University Daytona Beach, Florida

Member: Dr. Mark Thomsen
United States Air Force
Ogden, Utah

Member: Jacob Warner
United States Air Force
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C. SUMMARY

On April 4, 2018, at 0953 eastern daylight time, a Piper PA-28R-201, N106ER, collided with terrain following an in-flight breakup shortly after takeoff from Daytona Beach International Airport (DAB), Daytona Beach, Florida. The airline transport pilot and private pilot were fatally injured, and the airplane was destroyed. The airplane was registered to and operated by Embry-Riddle Aeronautical University and operated under the provisions of 14 Code of Federal Regulations Part 91 as an instructional flight. Day visual meteorological conditions prevailed at the time of the accident, and no flight plan was filed for the local flight, which departed DAB at 0927.

D. DETAILS OF THE INVESTIGATION

1.0 Airplane Overview

The Piper PA-28R-201 Arrow III is a single engine, low wing, all metal airplane with a conventional tail and retractable tricycle landing gear (Figure 1[1]). The airplane is 24 feet, 8.16 inches long, 7 feet, 10.20 inches tall at the tail, and has a wingspan of 35 feet, 5.04 inches. The airplane is powered by a Lycoming IO-360 reciprocating 4-cylinder engine with a McCauley 2-blade constant-speed tractor propeller. The airplane is used by many flight schools for complex aircraft flight training.

The all metal wings are designed with a main spar located near the mid-chord point and an aft spar at the aft end of the main wing box. Each wing is attached to the fuselage at 3 locations, the main spar, the aft spar, and the leading edge. The wing main spar fits into the center wing box and is fastened with 8 vertical bolts in the upper spar cap and 10 vertical bolts in the lower spar cap (Figure 2). A single horizontal bolt is installed through the wing and fuselage fittings at both the leading edge and aft spar. The main spar fastener locations are identified with a letter denoting location on the spar caps and numbered sequentially from outboard to inboard (Figure 3) in Section 57-40-00 of the Piper PA-28R-201 Airplane Maintenance Manual. The locations on the upper spar cap forward of the spar web are identified A-1 through A-4 and the locations on the upper spar cap aft of the web are identified B-1 through B-4. The locations on the lower spar cap forward of the spar web are identified C-1 through C-5 and the locations on the lower spar cap aft of the spar web are identified D-1 through D-5. An additional identifier for left or right (L or R) is added for this report.

[1] All Figures are presented in Appendix A.

2.0 Wreckage Examination

The left wing separated from the airplane at the wing root during the accident sequence and was recovered about 200 feet from the main wreckage which included the remainder of the airplane. The left wing main spar lower cap was fractured through the outboard fastener holes (LC-1 and LD-1) and the upper spar cap was fractured about 1.5 inches outboard of the outboard attach holes. Examination of the left wing main spar lower cap fracture showed a flat fracture face, dark deposits, and crack arrest features indicative of pre-existing progressive fracture (Figure 4). Both the inboard and outboard sides of the aft spar attach point remained intact with the fastener installed and the attach point was attached to the main fuselage wreckage. A section of the left wing aft spar about 12 inches long was pulled from the left wing. Both the inboard and outboard sides of the leading edge attach point remained intact with the fastener installed and the attach point was attached to the left wing wreckage. A section of the leading edge attach point structure was pulled from the fuselage.

The wing main spar center section box assembly was cut from the airplane along with about 18 inches of the right wing main spar which remained partially attached to the center section. The inboard 18 inches of the left wing main spar was cut from the separated left wing. All of the main spar wreckage was transported to the NTSB Materials Laboratory in Washington, DC. The leading edge and aft spar attach points were not retained.

The retained wreckage was examined by the Structures Group and NTSB Materials Lab personnel April 10-12, 2018. See NTSB Materials Laboratory Factual Report 18-061 in the public docket for the details of the lab investigation.

All of the wing attachment bolts on the accident airplane remained intact and installed. The bolts were all P/N NAS6606 with the correct dash length in accordance with the drawing. The torque striping on all the bolt heads and nuts was intact with no evidence of movement.

3.0 Registration and Maintenance

According to Piper Aircraft, Inc. (Piper) records, the accident airplane, N106ER, and the sister airplane, N104ER, were 2 of 8 airplanes (S/N 2844131-2844138) manufactured and certificated in 2007.

3.1 N106ER[2]

The accident airplane, S/N 2844137, was manufactured by Piper in 2007 and received its Airworthiness Certificate in the Normal category on September 17, 2007, with 5.8 hours accrued. The airplane was registered as N712ER at the time of manufacture. Embry Riddle Aeronautical University (ERAU) purchased the accident airplane from Piper on September 25, 2007, and subsequently sold it to a leasing company, AVN Air, LLC, on September 28, 2007. ERAU leased the airplane from AVN until September 4, 2015, when they purchased it back from the lessor. The airplane registration number was changed from N712ER to N106ER on July 10, 2014. According to ERAU, they had operated the airplane since manufacture and it had always been used for training of certified flight instructors and commercial pilots. The airplane was never used for initial

[2] See Attachment 1 to this report for the pertinent maintenance records from N106ER.

flight training.

The airplane had accrued 7,690.6 hours time-in-service prior to the accident flight. The airplane had accumulated 33,276 landings prior to the accident flight based on ERAU information documented in their Education and Training Administration program.

The discrepancy record for the accident airplane was examined for the life of the airplane beginning in October 2007 and including the 2 most recent discrepancy sheets that were found in the wreckage. The discrepancy record provides an avenue for pilots to inform maintenance technicians of issues with the airplanes. Most items logged in the discrepancy record did not result in a maintenance logbook entry. Each item was rectified and signed off in the discrepancy record. The last recorded discrepancy was entered on March 24, 2018. On 22 occasions, a pilot entered a flap overspeed in the discrepancy log with a range of 5-17 knots. In each case the discrepancy was signed off after inspection with no defects noted. On 7 occasions, a pilot entered a gear overspeed in the discrepancy log with a range of 2-11 knots. In each case the discrepancy was signed off after inspection with no defects noted. On 18 occasions, a pilot entered a hard landing in the discrepancy log and, in each case, the discrepancy was signed off after inspection with no defects noted. The hard landing entered on January 15, 2014, included a note that the left main tire blew.

The airframe maintenance logbook was examined for the life of the airplane. The airframe was inspected every 50 hours alternating between an ERAU 50-hour inspection and an ERAU annual inspection. The ERAU annual inspection contained all the provisions in the Piper recommended annual inspection with some items added by ERAU. Hard landing inspection entries were found in the airframe logbook in 4 records, dated 2/17/11, 8/24/11, 11/11/11, and 11/14/11. These 4 dates corresponded with a hard landing entry in the discrepancy log. In each case there were no defects noted or it was determined that the landing was not hard. The tach was changed on the airplane twice, once in September 2011 when the airframe had accrued 3019.0 hours and once in February 2018 when the airframe had accrued 7612.7 hours. On July 15, 2014, the logbook entry stated that the airplane was stripped and repainted coincident with the registration change to N106ER. Logbook entries on March 31, 2015, and January 9, February 13, April 25, and July 11, 2017, detailed maintenance to replace rivnuts, covers, or screws on the lower wing main spar bolt covers. There were no indications of airplane damage, major repairs, or other significant non-standard maintenance noted in the logbook.

The most recent inspection of the airplane was an annual inspection that occurred on March 22, 2018, at an airframe time of 7,662.3 hours. All of the items in the inspection list were signed off by a mechanic and/or inspector. There were no discrepancies generated pertaining to the wing spars. Section F, step 13, in the ERAU 100 hour/annual inspection states "Inspect wing spar to fuselage attachment bolts and brackets." This item was signed off. According to ERAU the accomplishment of this item would involve removing the plastic covers over the main spar attach bolts on the lower wing surface to make sure the torque striping on the nuts was not broken. The ERAU inspection would not normally look at the head of the bolts inside the center section even though the airplane interior would be removed.

The most recent 50-hour inspection occurred on February 27, 2018, at an airframe time of 7,613.4 hours. All of the items in the inspection list were signed off by a mechanic. There were no

discrepancies generated pertaining to the wing spars. The AD compliance list was examined and showed that all applicable AD's had been complied with. The airplane was weighed after manufacture and had not been weighed since. The most recent calculated weight and balance report for the airplane listed an empty weight of 1,842.14 pounds with a CG position at 86.28 inches yielding a useful load of 907.86 pounds.

An examination of the engine and propeller logbooks was performed with no findings pertinent to this investigation.

3.2 N104ER[3]

The sister airplane, S/N 2844135, was manufactured by Piper in 2007 and received its Airworthiness Certificate in the Normal category on July 18, 2007, with 5.2 hours accrued. The airplane was registered as N710ER at the time of manufacture. ERAU purchased the airplane from Piper on July 20, 2007, and subsequently sold it to a leasing company, AVN Air, LLC, on September 28, 2007. ERAU leased the airplane from AVN until September 4, 2015, when they purchased it back from the lessor. The airplane registration number was changed from N710ER to N104ER on June 17, 2014. According to ERAU, they had operated the airplane since manufacture and it had always been used for training of certified flight instructors and commercial pilots. The airplane was never used for initial flight training.

The airplane had accrued 7,660.7 hours time-in-service and 33,288 landings (documented in the ERAU Education and Training Administration program) as of April 9, 2018.

The discrepancy record was not examined for N104ER. The airframe maintenance logbook was examined for the life of the airplane. Like the accident airplane, the airframe was inspected every 50 hours alternating between an ERAU 50-hour inspection and an ERAU annual inspection. Two hard landing inspections were found in the logbook, one dated March 22, 2012, and one dated April 25, 2012. In both cases the inspection determined that the landing was not hard and there were no discrepancies noted. On June 16, 2014, the logbook entry stated that the airplane was stripped and repainted coincident with the registration change to N104ER. The most recent inspection of the airplane was a 50-hour inspection that occurred on March 29, 2018, at an airframe time of 7,649.0 hours. The most recent annual inspection occurred on March 7, 2018, at an airframe time of 7,603.0 hours. In both cases, the inspection entry in the logbook was signed off and the airplane was returned to service. The engine mount was replaced in November 2015 with a repaired unit for unknown reasons. There were no other indications of airplane damage, major repairs, or other significant non-standard maintenance noted in the logbook.

The engine and propeller logbooks were not examined for N104ER.

4.0 Tests and Research

4.1 ERAU

After the accident, ERAU performed a visual inspection of another Piper PA-28R-201 airplane in their fleet, N104ER, and found no obvious indications of cracking in the wing spar caps. ERAU contracted a local nondestructive testing (NDT) agency, Power/Aviation, Inc., to perform a high

[3] See Attachment 2 to this report for the pertinent maintenance records from N104ER.

frequency eddy current (HFEC) bolt hole inspection of the left and right lower outboard wing attach bolt holes (holes C-1 and D-1). The agency is an FAA approved repair station for nondestructive inspection, testing, and processing. Power/Aviation, Inc., performed a HFEC inspection of the left and right lower outboard wing attach bolt holes with a 3/8-inch bolt hole probe on April 9, 2018, with the wings installed on the airplane and reported "No relevant indications". The wings were removed from N104ER on April 10, 2018, for further inspection.

The Structures Group convened April 18-19, 2018, to perform a follow up HFEC inspection of the wing attach bolt holes on N104ER. Piper supplied two company personnel for the inspection, one an American Society for Nondestructive Testing (ASNT) Level III ultrasonic testing (UT) certified engineer and one an ASNT Level II inspector. The inspections were performed with a Nortec 500D Eddy Current Unit and an Olympus 90º surface probe 0.062" shielded coil. The unit was calibrated using National Institute of Standards and Technology (NIST) traceable bolt hole and surface calibration standards. The bolt hole standard had a 0.030-inch by 0.030-inch corner notch and a 0.030-inch radial notch and the 2024-T3 aluminum surface standard had 0.008-inch, 0.020-inch and 0.040-inch notches. A frequency of 300 KHz was used with the gain set to show a 5 division change at the largest calibration notch.

The inspection revealed a crack indication with the HFEC surface probe on the forward side of the left wing lower forward outboard wing attach bolt hole, LC-1 (Figure 5). The indication exceeded 0.040-inch depth from the lower surface of the lower spar cap and exceeded 0.040-inch length forward of the hole. The crack was visible under a 10x hand loupe. The remaining holes in the left wing upper and lower spar caps had no indications. The right wing upper and lower spar caps were also inspected with no indications.

The wings were re-installed on airplane N104ER in order to validate a proposed HFEC inspection procedure for the wing attach bolt holes. The same Piper personnel and equipment was used for the re-inspection with the exception that an Olympus 3/8-inch bolt hole probe 0.062-inch shielded coil was used instead of the surface probe[4]. The inspection was performed on May 8, 2018 and confirmed the crack indication in hole LC-1. The inboard portion of the left wing main spar was cut from the wing of N104ER and sent to the NTSB Materials Lab for examination. See NTSB Materials Laboratory Factual Report 18-061 for the details of the exam.

Another ERAU airplane, N102ER, was made available for inspection during the April 18-19, 2018, visit. The airplane, S/N 2844081, was manufactured in March 2012 and had accrued 5,864.6 hours and 15,808 cycles at the time of the inspection. The right and left lower outboard wing attach bolts (locations C-1 and D-1) were removed for the inspection and the airplane was resting on its landing gear. HFEC surface probe inspections of holes LC-1, LD-1, RC-1, and RD-1 produced no indications. The maintenance records were not examined for N102ER.

ERAU made the remaining 5 airplanes in their fleet available for inspection by the Piper personnel under the guidance of the Structures Group on June 6, 2018. The inspections were performed with the wings installed, the airplanes resting on their landing gear, the bolts removed from holes LC-1, LD-1, RC-1, and RD-1, and using the HFEC bolt hole probe described above. The maintenance

[4] All of the HFEC inspections detailed in this section were performed by the same Piper personnel with the same equipment using either the surface probe or bolt hole probe as noted.

records were not examined for these airplanes.

Airplane N108ER, S/N 2844147, was manufactured in July 2014 and had accrued about 2,829 hours and 10,930 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes. The initial inspection of RD-1 exhibited a noisy response but was clear after cleaning and re-inspection.

Airplane N110ER, S/N 2844148, was manufactured in July 2014 and had accrued about 2,905 hours and 11,008 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes.

Airplane N115ER, S/N 2844149, was manufactured in July 2014 and had accrued about 2,779 hours and 10,646 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes.

Airplane N116ER, S/N 2844150, was manufactured in July 2014 and had accrued about 2,887 hours and 11,165 cycles at the time of the inspection. No crack indications were noted during the inspection of holes LC-1 and RD-1 but hole LC-1 appeared slightly elongated in the spanwise direction. Hole LD-1 exhibited a possible indication on the aft side of the hole with the HFEC bolt hole probe that was confirmed with the HFEC surface probe. Visual inspection of the hole revealed the presence of a small circumferential score consistent with a thread impression that was confirmed to coincide with the location of the indication. Hole RC-1 exhibited a noisy response and a possible indication with the HFEC bolt hole probe that was confirmed with the HFEC surface probe. Visual inspection of the hole revealed the presence of a larger circumferential score consistent with a thread impression that was confirmed to coincide with the location of the indication.

Airplane N117ER, S/N 2844151, was manufactured in July 2014 and had accrued about 2,856 hours and 11,193 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes.

4.2 Florida Institute of Technology (FIT)

FIT in Melborne, FL, made their 2 Piper PA-28R-201 airplanes available to the group for inspection on April 19, 2018. The airplanes were inspected by Piper personnel under the guidance of the Structures Group using the HFEC surface probe described above. The airplanes had been previously inspected by Powers/Aviation, Inc., using a HFEC bolt hole probe with no findings. Airplane N772FT, S/N 2844029, was manufactured in 2000 and had accrued 9,119.9 hours and about 39,000 cycles at the time of the inspection. FIT does not track landing cycles on their airplanes, but their research has shown they accrue about 4.27 landings for every flight hour. According to FIT, they had operated the airplane since manufacture and it had always been used for training of certified flight instructors and commercial pilots. The wings had been removed from the airplane prior to the inspection. The maintenance records were not examined for this airplane and FIT reported there were no recorded hard landings or prior wing removals in the airplane maintenance records. HFEC surface probe inspections of holes LC-1, LD-1, RC-1, and RD-1 produced no indications. The right and left wing upper and lower spar caps exhibited evidence of fretting, surface scratches, and washer impressions on the forward and aft doubler flanges.

Airplane N773FT, S/N 2844030, was manufactured in 2000 and had accrued 8,486.9 hours and about 36,000 cycles at the time of inspection. No crack indications were noted during the inspection of the 4 holes. The torque on the left and right outboard lower nuts met the minimum of 30 ft-lb. The maintenance records were not examined for this airplane and FIT reported there were no recorded hard landings or prior wing removals in the airplane maintenance records.

4.3 Flight Safety International (FSI)

FSI in Vero Beach, FL, made 5 Piper PA-28R-201 airplanes available for inspection by the group on May 3, 2018. All 5 airplanes were purchased from private operators and had been retired from service at FSI. The inspections were performed using a HFEC bolt hole probe under the guidance of the Structures Group. The left and right lower outboard attach bolts were removed prior to the group's arrival to facilitate the inspection. FSI does not track flight/landing cycles in their operation. The group estimated the cycles on the airplane by assuming 1 cycle per hour in private operations and 4 cycles per hour in flight training operations. According to FSI the airplanes were used for training of certified flight instructors and commercial pilots. The maintenance records were not examined for these airplanes.

Airplane N101WF, S/N 28R-7837125, was manufactured in 1978 and had accrued 10,301.5 hours (8,884.0 hours at FSI) and an estimated 36,953 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes.

Airplane N31927, S/N 28R-7837257, was manufactured in 1978 and had accrued 9,237.4 hours (7,113.8 hours at FSI) and an estimated 30,578 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes.

Airplane N44838, S/N 28R-7737142, was manufactured in 1977 and had accrued 8,819.0 hours (7,295.1 hours at FSI) and an estimated 30,704 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes.

Airplane N5981V, S/N 28R-7737078, was manufactured in 1977 and had accrued 10,148.6 hours (7,218.7 hours at FSI) and an estimated 31,804 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes.

Airplane N88PT, S/N 28R-7837108, was manufactured in 1978 and had accrued 9,421.2 hours (8,307.3 hours at FSI) and an estimated 34,343 cycles at the time of the inspection. No crack indications were noted during the inspection of the 4 holes.

4.4 Texas State Technical College (TSTC)

TSTC made 2 Piper PA-28R-201 airplanes available for inspection by the group on May 10, 2018. The inspections were performed using the HFEC bolt hole probe under the guidance of the Structures Group. The left and right lower outboard attach bolts were removed prior to the group's arrival to facilitate the inspection. TSTC does not track flight/landing cycles in their operation. The group estimated the cycles on the airplanes by assuming 1 cycle per hour in private operations and 4 cycles per hour in flight training operations. According to TSTC the airplanes were used for training of certified flight instructors and commercial pilots.

Airplane N228TX, S/N 2844136, was manufactured in 2007 and had accrued 3,923.9 hours and an estimated 15,695 cycles at the time of the inspection. TSTC has operated the airplane since new. The maintenance records documented a gear up landing in November 2009 at an airframe time of 748.6 hours. There was no damage to the wing spars noted in the records. No crack indications were noted during the inspection of the 4 holes.

Airplane N149DT, S/N 2844125, was manufactured in 2005 and had accrued 2,777.5 hours (2,021.3 hours at TSTC) and an estimated 8,841 cycles at the time of the inspection. The maintenance records documented a hard landing in June 2016 at an airframe time of 1,926.1 hours. Several landing gear components were replaced according to the records but there was no damage to the wing. No crack indications were noted during the inspection of the 4 holes.

4.5 L3 Airline Academy (L3)

L3 in Sanford, FL, informed the group about a retired Piper PA-28R-201 airplane at their facility. The airplane N3986M, S/N 28R-7837150, was manufactured in 1978 and had accrued 9,841.3 hours and an unknown number of cycles. The right wing was removed and sent to ERAU. The group was able to perform a HFEC inspection with the bolt hole probe of the right wing main spar lower cap holes at ERAU with no findings. The inboard portion of the right wing main spar was cut from the wing and sent to the NTSB Materials Laboratory for examination. See NTSB Materials Laboratory Factual Report 18-061 for the details of the exam. The maintenance records were not examined for this airplane.

L3 was also operating 6 additional Piper PA-28R-201 airplanes for flight training. The airplanes were all manufactured in 1977 or 1978 and had accrued between 7,147 hours and 9,234 hours. The airplanes were not in service with L3 for their entire life and the accrued cycles was unknown. L3 had a HFEC bolt hole inspection performed on all the airplanes by Powers/Aviation, Inc., with "no relevant indications" on any of the airplanes. The Structures Group was not present for these inspections and the maintenance records were not examined for these airplanes.

4.6 Previous Accidents

FTW87FA088

On March 30, 1987, at 1257 central standard time, a Piper PA-28-181, N8191V, was destroyed when it collided with the ground following an in-flight left wing separation while in low level cruise flight near Marlin, TX. The airplane was owned and operated by the Griffin Pipeline Patrol Company and was performing a pipeline patrol flight when the accident occurred. The investigation found fatigue cracking in the left wing main spar lower cap near the forward, outboard attach hole (LC-1). The fatigue cracking initiated on the lower surface of the lower spar cap and intersected the outboard edge of hole LC-1. The fatigue cracking had progressed from the hole forward through the forward flange and aft about halfway through the lower spar cap. The NTSB issued recommendations A-87-40, -41, and -42 to the FAA as a result of the preliminary findings from the investigation on April 10, 1987. The recommendations asked for an AD to immediately inspect the lower spar caps on certain PA-28 model airplanes, a recurrent periodic inspection, and a study to determine the other Piper airplanes with a similar spar design. The accident factual report, Materials Laboratory Report 87-89, recommendation letter, and final report from this 1987 accident are included in the docket for the current accident.

NYC93FA140
On August 24, 1993, at 2234 eastern daylight time, a Piper PA-28-181, N2093A, was destroyed when it collided with a vehicle and a tree following an in-flight right wing separation while circling at low level near Provincetown, MA. The airplane was maneuvering in clouds after the visual flight rules rated pilot entered instrument meteorological conditions after takeoff. The investigation found fatigue cracking in the right wing main spar lower cap near the forward outboard attach hole (RC-1). The fatigue cracking initiated on the lower surface of the lower spar cap slightly aft and outboard of the edge of hole RC-1 but did not intersect the hole prior to the spar failure. The fatigue crack measured about 0.3-inch long spanwise with a maximum depth of about 0.2-inch. The fatigue cracking initiated in an area adjacent to the hole where there was wear and fretting damage. Several other cracks were noted in the lower surface of the spar cap parallel to the fatigue zone near both hole RC-1 and hole RD-1. The investigation also found that the nuts used on the wing attach bolts were incorrect. The wings on the accident airplane were removed and inspected in May 1987 in accordance with AD 87-08-08. The full accident report and Metallurgist's Factual Report 94-34 from this 1993 accident are included in the docket for the current accident.

4.7 Hurricane Info
The ERAU campus in Daytona Beach, FL, has been impacted by two hurricanes since 2007, Matthew in October 2016 and Irma in September 2017. ERAU has published a Hurricane/Severe Weather plan for their aircraft in its Emergency Response Plan. ERAU aircraft that are able to fly will be evacuated to a safe location prior to storm arrival according to the plan. In October 2016, the ERAU fleet was moved to Auburn University Regional Airport (KAUO) in Auburn, AL. In September 2017 part of the ERAU fleet was moved to KAUO while the Piper PA-28R-201 airplanes were moved to Birmingham-Shuttlesworth International Airport (KBHM), Birmingham, AL, including N106ER and N104ER. Two of the Cessna airplanes at KAUO in September 2017 were damaged by the remnants of hurricane Irma that impacted Auburn.

5.0 FAA Information

In response to the NTSB recommendation letter issued after the 1987 PA-28-181 accident, the FAA issued AD 87-08-08 in April 1987, requiring the inspection of the main wing spar lower caps on all PA-28, PA-32-260, and PA-32-300 model airplanes. The AD required removing the wings and performing a visual and dye penetrant inspection of the lower spar caps, replacing any wing spars found to be cracked, and performing a visual inspection of the upper wing skins for cracks. In August 1987, the FAA issued revised AD 87-08-08R1 to remove the Piper PA-28-201T airplanes from the affected group since it had a different spar design. In September 1987, the FAA issued revised AD 87-08-08R2 to suspend the effectivity of the AD while they reevaluated the issue and examined additional data. In May 1989, the FAA issued revised AD 87-08-08R3 that rescinded the original AD and revisions R1 and R2. In the discussion published for the rescission, the FAA stated that they had inspection results from about 560 airplanes with only two Piper PA-32-300 airplanes reported with spar cracks. Further examination of the airplanes with reported cracks showed they were operated overweight, operated in a severe environment, and had documented damage and repairs. The FAA examined fatigue test data and a fracture mechanics analysis from Piper and concluded that the cracks found on the two airplanes were isolated

occurrences and not likely to exist or develop in other PA-28 and PA-32 series airplanes operated in a normal environment. The FAA maintained in the rescission that instructions provided in the FAA-approved Piper SB 886 would address the inspection of the wing spars for those PA-28 and PA-32 series airplanes that were operated in a severe environment.

Title 14, *Code of Federal Regulations*, 91.409 provides the inspection requirements for airplanes and 91.409(b) is applicable to the airplanes operated by ERAU. 91.409(b) states "no person may operate an aircraft carrying any person (other than a crewmember) for hire, and no person may give flight instruction for hire in an aircraft which that person provides, unless within the preceding 100 hours of time in service the aircraft has received an annual or 100-hour inspection and been approved for return to service in accordance with part 43 of this chapter or has received an inspection for the issuance of an airworthiness certificate in accordance with part 21 of this chapter. The 100-hour limitation may be exceeded by not more than 10 hours while enroute to reach a place where the inspection can be done. The excess time used to reach a place where the inspection can be done must be included in computing the next 100 hours of time in service."

The Piper PA-28R-201 was type certificated under Part 3 of the Civil Air Regulations (CAR) according to Type Certificate Data Sheet (TCDS) 2A13. The only fatigue requirements in CAR 3 effective for the airplane were that the design details should avoid stress concentrations.

The FAA published guidance in Advisory Circular (AC) 23-13A in 2005 to show an acceptable means of compliance with the Part 23 regulations for fatigue, fail-safe, and damage-tolerance evaluations of metallic airplane structure. The AC contains approved flight and ground load spectra for several different types of airplanes and usages. The maneuver spectra for single engine basic instruction usage, single engine personal usage, and survey (pipeline patrol) usage are plotted together in Figure 6. The gust spectra for single engine unpressurized operation (including personal usage and basic instruction usage) and survey (pipeline patrol) usage are plotted together in Figure 7.

In response to the preliminary findings from this investigation, the FAA issued a Notice of Proposed Rulemaking (NPRM) for a new AD applicable to most Piper PA-28 model, all PA-28R model, and most PA-32 model airplanes. The proposed AD would require calculating the factored service life for the main wing spar, inspecting the main spar lower outboard attach holes for cracks at a specified time, and replacing any cracked main wing spars. The NTSB submitted comments to the FAA regarding the NPRM.

6.0 Piper Aircraft, Inc. Information

Piper has published maintenance information for the PA-28R-201 in the Airplane Maintenance Manual (AMM). Chapter 4 of the AMM specifies that "No limitations, related to fatigue life of the airplane and its components, have been established for the PA-28R-201 Arrow airplane" and there are no mandatory structural inspection intervals.

Chapter 5 of the AMM provides recommended inspection items for a 50-hour and 100-hour inspection. The 100-hour inspection is a complete inspection of the airplane and is identical in scope to an annual inspection. The inspection is broken up into major groups that includes a Wing

Group in Section E. Item 13 in the Wing Group states, "Inspect wing spar to fuselage attachment bolts and brackets" and is recommended every 100 hours. Procedures for a detailed inspection of the wing spars are included in section 57-10-00 of the AMM. The procedure defines airplane usage classes of normal, severe, extreme, and unknown. The normal usage class will encompass most aircraft and includes airplanes operated in normal flight training operations. The recommended inspection involves removing the wings from the airplane, visually inspecting the lower spar caps with a 10-power magnifying glass and performing a dye-penetrant inspection of the spar caps. The Special Inspections section of the AMM (5-30-00) recommends that the wing spar inspection in 57-10-00 be performed beginning at 30,600 hours, and every 3,000 hours thereafter, for airplanes in the normal usage class.

Chapter 5-50-00 of the AMM provides instructions for Unscheduled Maintenance Checks. Section 3 provides instructions for inspection of the airplane after a hard or overweight landing. In addition to inspection of the landing gear, landing gear attach points, and wheel wells, there are instructions to inspect the wings internally and externally. The instructions call for inspection of "Wing attach bolts for slippage, damage and overstress. Upper and lower wing skins for wrinkles, cracks, popped or loose rivets. Remove access plates and inspect for internal damage to ribs, stringers and sparwebs; and fuel tanks for damage, attachment, and leaks."

Piper published Service Letter (SL) 997 in May 1987 to supplement AD 87-08-08. The SL provided instructions for the removal and reinstallation of the wings on all PA-28, PA-28R, and PA-32 series airplanes. Warnings were included in the SL to use extreme care when removing and reinstalling the wing attach hardware to preclude damaging the holes.

Piper published Service Bulletin (SB) 886 in June 1988 after the original issuance of AD 87-08-08 and the subsequent rescission of the AD to provide instructions for inspecting the wing main spar on certain PA-28, PA-28R, and PA-32 model airplanes. Piper considered the FAA-approved SB instructions mandatory. The SB was developed based on report LG88ER0016, "Piper Aircraft Model PA28-181 and PA32-300 Main Spar Fracture Analysis" provided by Lockheed-Georgia Company under contract to Piper in January 1988. The fracture analysis was done in response to the 1987 accident. The SB divided the airplanes up into two groups and defined 4 usage classes, A through D, based on an accounting of the lifetime usage to determine the inspection compliance times. Class A, Normal Usage, was applicable for those airplanes that did not fall into any other usage class and would encompass most airplanes. Normal flight training would fall into this usage class. Class B, Severe Usage, was applicable for those airplanes that had ever been engaged in contour or terrain following operations such as powerline/pipeline patrol, fish/game spotting, aerial application, aerial advertising, police patrol, livestock management, or others where a significant portion of the flight time was spent below 1000 feet AGL altitude. Class C, Extreme Usage, was applicable for those airplanes that had been damaged due to operation from extremely rough runways, flight in extreme damaging turbulence, accidents or incidents which required major repair or replacement of wings, landing gear, or engine mounts. Class D, Unknown Usage, was applicable for those airplanes where the operational or maintenance history was unknown. Instructions were provided for calculating a factored service life for airplanes that had a mixture of Class A and B usage. A table was provided to specify the initial inspection time and recurring inspection interval once the airplane group and usage class was determined. Class A airplanes had an initial inspection time of 30,600 hours or 62,900 hours depending on the group. Class B or

mixed Class A and B airplanes had an initial inspection time of 1,800 factored hours or 3,700 factored hours depending on the group. Class C and D airplanes had an initial inspection time within 50 hours time-in-service from the issuance of the SB. The contents of SB 886 were incorporated into Chapter 5 of the AMM.

Piper published SB 978A in August 1999 that was identical to SB 886 but added additional PA-28 and PA-28R model airplanes that were not manufactured at the time SB 886 was published.

Many of the Piper Cherokee based airplanes have the same or a similar spar configuration to the PA-28R-201 accident airplane at the wing attach location. The spar configuration for the PA-28-140/-150/-151/-160/-161/-180/-181/-235, the PA-28R-180/-200/-201T, the PA-28RT-201/-201T, and the PA-32-260/-300[5] airplanes is identical to the accident airplane. The spar configuration on the remaining unlisted PA-28, PA-32, PA-34, and PA-44 model airplanes, while similar, utilizes additional structural elements and/or different fasteners that differentiates the spar configuration. After the accident, the Piper engineering group performed substantial fatigue analysis work to try to understand the potential risk to the rest of the Cherokee airplanes. The proprietary analysis results were shared with the group and showed that there can be a significant reduction in fatigue life at the main wing spar lower outboard attach hole due to the higher loads on an airplane in the flight training environment. Each of the airplane models above with an identical spar configuration was compared to the accident airplane and showed that the PA-28R-180/-200/-201T, the PA-28RT-201/-201T, and the PA-32-260/-300 airplanes have similar loads and fatigue lives to the PA-28R-201 and warrant further consideration, especially if operated in the training environment. The analysis for all of the PA-28 (fixed gear) airplanes showed that the loads were significantly less, and the resulting fatigue lives were significantly higher than the PA-28R-201 with the exception of the PA-28-235/-236 airplanes. The analysis for the PA-28-235/-236 airplanes indicated that the fatigue lives when operated in the training environment are similar to the PA-28R-201. However, Piper maintains that these airplanes are unlikely to be operated in the training environment due to their higher operational costs.

7.0 United States Air Force (USAF) Analysis

Members of the A-10 Aircraft Structural Integrity Program (ASIP) were added to the group to provide their experience and expertise in dealing with aging aircraft and fatigue issues in aluminum aircraft wing structure. The ASIP team was given all of the information from the Materials Lab portion of the investigation, the historical information on the fatigue analysis done after the 1987 accident, and the results of the inspection of the additional airplanes and asked to perform an independent analysis of the accident airplane failure using the methods they have perfected for use on the A-10 airplane. A presentation of the results of the USAF work is contained in Attachment 3 to this report and summarized here.

The USAF first examined the historical usage of the two ERAU airplanes and developed a load spectrum based on the information contained in the Lockheed report from the previous 1987

[5] The PA-32-300 airplanes SN 32-7940001 to 32-7940290 have a reinforced spar configuration that is not identical to the PA-28R-201.

accident. A preliminary crack growth analysis was performed using AFGROW[6] to validate the assumptions, load spectrum, and stress levels. A finite element model of the main spar lower cap was created in StressCheck® and validated for use in obtaining the internal stresses in the lower spar cap. The USAF then used the Broad Application for Modeling Fracture (BAMF) to tie AFGROW and StressCheck® together and provide a 3-D structural representation of the lower spar cap. The BAMF analysis was run several times to examine the effect of initial flaw size and fastener fit on the fatigue crack growth in the lower spar cap. The model results were then compared to the evidence from the accident airplane, N106ER, and the sister airplane, N104ER.

Examination of the usage information for the two ERAU airplanes showed that the average flight time for the airplanes was about 14 minutes over the course of their lifetimes with ERAU in the flight training environment. Combining this average flight time with the normal climb and descent rates for the PA-28R shows that the airplanes likely never reached altitudes greater than 2,500 feet AGL in normal operation on an average flight. Since peak gust velocities are inversely proportional to altitude (Slide 9), the airplanes spent much of their life in a more severe gust environment similar to the pipeline patrol gust environment detailed in the Lockheed report. The maneuver loads for the flight training mission are less than the pipeline patrol mission detailed in the Lockheed report. Initially, the USAF used a maneuver load spectrum with the same shape as the pipeline patrol but with a peak stress reduced from 31 ksi to 14 ksi. A full load spectrum was developed and included taxi, gust, maneuver (severity reduced from pipeline patrol in the Lockheed report), and landing loads.

The accident airplane had 3 separate fatigue cracks in the left wing main spar lower cap that all initiated at or near the lower corner of a fastener hole. The NTSB was unable to determine which crack initiated first. The USAF identified the crack initiating at the lower forward corner of hole LC-1 as Crack 1, the crack initiating at the lower aft corner of hole LC-1 as Crack 2, and the crack initiating at the lower aft corner of hole LD-1 as Crack 3. The USAF performed several analyses with varying initial flaw sizes at each location and with an open or filled hole configuration. The results showed that the initial flaw size has a significant effect on the fatigue life, the crack growth rate increases significantly once the size reaches about 0.050-inch, and the filled hole provides a life improvement on the order of 1.5.

The USAF also examined the damage tolerance of the lower cap realizing that there is an unknown portion of the fatigue life of the spar cap prior to fatigue crack initiation and propagation to a detectable size. The non-destructive inspection (NDI) method chosen will have differing detectable size limits. The build up of the wing spar in the area of interest lends itself to NDI using HFEC with a manual right angle probe, a manual bolt hole probe, or a semi-automated bolt hole probe. The USAF has not accepted a manual HFEC bolt hole inspection method for years due to no established probability of detection (PoD), greatly reduced sensitivity, and human factor variables. Their PoD data indicates that the detectable flaw size for an HFEC inspection with a semi-automated bolt hole probe is 0.050-inch. If they were to use a manual probe the assumed detectable flaw size would be 0.250-inch. Using the crack growth data and the detectability limit for a manual probe showed that a significant portion of the fatigue life is gone before the crack

[6] AFGROW is a Damage Tolerance Analysis (DTA) software package originally developed by the Air Force Research Laboratory that allows users to analyze crack initiation, fatigue crack growth, and fracture to predict the life of metallic aircraft structures.

becomes detectable leaving little margin for repeat inspections. They estimated that the sister airplane, N104ER, with a fatigue crack measured at 0.18-inch was less than 2,000 hours from failure.

The USAF also did some analysis to examine the crack growth prediction sensitivity to load spectrum differences. Many assumptions must be made when generating a load spectrum in the absence of recorded data. There could be a wide variation in fatigue life depending on the assumptions made. In order to more accurately predict the fatigue life, they would need to utilize a load spectrum based on recorded flight data.