Loss of Control at Takeoff
Air Methods Corporation
Airbus Helicopters AS350 B3e, N390LG
Frisco, Colorado
July 3, 2015

Accident Report

NTSB/AAR-17/01
PB2017-101425

National
Transportation
Safety Board

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490 L'Enfant Plaza, S.W.
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Abstract: This report discusses the July 3, 2015, accident in which an Airbus Helicopters AS350 B3e, N390LG, registered to and operated by Air Methods Corporation, crashed into a parking lot shortly after lifting off from the Summit Medical Center Heliport, Frisco, Colorado. The pilot was fatally injured, and the two flight nurses onboard were seriously injured. The helicopter was destroyed by impact forces and a postcrash fire. Safety issues discussed in this report relate to the lack of a cockpit alert to pilots to indicate the loss of hydraulic boost to the pedal controls for AS350-series helicopters with a dual hydraulic system, the need for changes to the tail rotor flight controls of AS350-series helicopters with a dual hydraulic system to ensure pedal control hydraulic assistance and mitigate the possibility of pilot error during hydraulic system checks, the lack of readily available information for helicopter operators and customers regarding safety equipment and systems that would enhance a helicopter's crashworthiness, the need for crash-resistant fuel systems for helicopters not covered by the November 1994 fuel system crashworthiness requirements, and the lack of requirements to install, on smaller aircraft, flight recorder systems that protect recorded data from crash impact damage and postcrash fire damage.

For more detailed background information on this report, visit http://www.ntsb.gov/investigations/dms.html and search for NTSB accident ID PB2017-101425. Recent publications are available in their entirety on the Internet at http://www.ntsb.gov. Other information about available publications also may be obtained from the website or by contacting:

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Abbreviations

91CO	Summit Medical Center Heliport
AAMS	Association of Air Medical Services
AC	advisory circular
ACCT	Association of Critical Care Transport
AD	airworthiness directive
agl	above ground level
AIDMOR	accident, incident, damage, malfunction, and operations report
AMOA	Air Medical Operators Association
ARAC	Aviation Rulemaking Advisory Committee
ASAP	aviation safety action program
AWOS	automated weather observing system
BEA	Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile
CFR	*Code of Federal Regulations*
CRFS	crash-resistant fuel system
EASA	European Aviation Safety Agency
EMS	emergency medical service
FAA	Federal Aviation Administration
FDM	flight data monitoring
FOQA	flight operational quality assurance
HAA	helicopter air ambulance
HEMS	helicopter emergency medical service
IOGP	International Association of Oil and Gas Producers
LTE	loss of tail rotor effectiveness
MDT	mountain daylight time
MSAP	maintenance safety action program

NTSB	National Transportation Safety Board
NVM	nonvolatile memory
RV	recreational vehicle
SAFO	safety alert for operators
SAIB	special airworthiness information bulletin
SB	service bulletin
SD	secure digital
SMS	safety management system
STC	supplemental type certificate
TSO	technical standard order

Executive Summary

On July 3, 2015, about 1339 mountain daylight time, an Airbus Helicopters AS350 B3e helicopter, N390LG, registered to and operated by Air Methods Corporation, lifted off from the Summit Medical Center Heliport, Frisco, Colorado, and then crashed into a parking lot; the impact point was located 360 feet southwest of the ground-based helipad. The pilot was fatally injured, and the two flight nurses were seriously injured. The helicopter was destroyed by impact forces and a postcrash fire. The flight was conducted under the provisions of 14 *Code of Federal Regulations* Part 135 on a company flight plan. Visual meteorological conditions prevailed at the time of the accident.

The AS350 B3e has a dual hydraulic system. The upper and lower hydraulic systems provide hydraulic assistance to the main rotor flight controls. This dual-hydraulic setup provides redundancy to the main rotor servo controls in case one of the hydraulic systems were to fail. The lower hydraulic system provides hydraulic assistance to the tail rotor flight controls. Because the tail rotor system has only a single-cylinder servo control, a yaw load compensator provides continuous hydraulic power assistance to the pedal controls in the event of a loss of pressure to the lower hydraulic system.

Operational procedures for the AS350 B3e required the pilot to perform a preflight hydraulic check to ensure that the yaw load compensator was functional. The steps of the check involved (1) moving the yaw servo hydraulic switch to the “OFF” position (which cuts off hydraulic pressure to the tail rotor hydraulic circuit) and then ensuring that pedal forces remained low; (2) depressing a test button on the cockpit center console, thereby releasing (depleting) the hydraulic pressure in the yaw load compensator accumulator by opening its solenoid valve, and then ensuring that loads were felt on the pedals; (3) resetting the test button, thereby closing the solenoid valve; and (4) restoring hydraulic pressure by moving the yaw servo hydraulic switch to the “ON” position.

The National Transportation Safety Board’s (NTSB) investigation determined that the pilot most likely did not return the yaw servo hydraulic switch to its “ON” position before takeoff, resulting in no hydraulic pressure in both the tail rotor servo control and the yaw load compensator accumulator, a lack of hydraulic boost to the pedals, and significantly increased pedal loads. Surveillance videos capturing the liftoff showed the helicopter yaw to the left and rotate counterclockwise several times before descending and impacting a recreational vehicle and the parking lot. Video evidence also showed that the pilot did not perform a hover check, as required by operational procedures, which could have allowed the pilot to verify the helicopter’s controllability.

A surveillance video capturing the helicopter’s descent and ground impact showed fuel flowing from the wreckage just after impact and then the onset of a postcrash fire. The postcrash fire consumed or severely damaged most of the helicopter and resulted in extensive thermal injuries to the pilot and one of the flight nurses. Although the helicopter was manufactured in March 2013, it was not subject to the improved crashworthiness requirements regarding crash-resistant fuel systems that became effective in November 1994. The helicopter was not subject to these requirements because it was certificated according to the regulations that were in effect in

December 1977, when the Federal Aviation Administration (FAA) provided initial type certificate design approval for AS350-series helicopters. In addition, although the helicopter was not required to be equipped with a flight recorder system, Air Methods voluntarily equipped the helicopter with an onboard image recorder. However, this recorder did not comply with the crash-resistance provisions of an FAA technical standard order (TSO) addressing the minimum performance standards for lightweight flight recorder systems, and the NTSB was unable to recover data from the recorder due to impact and postcrash fire damage.

The NTSB identified the following safety issues as a result of this accident investigation:

- **Lack of a cockpit alert to pilots to indicate the loss of hydraulic boost to the pedal controls for AS350-series helicopters with a dual hydraulic system.** In February 2015, Airbus Helicopters issued a service bulletin for AS350-series helicopters to incorporate a light on the caution and warning panel that would flash if the yaw servo hydraulic switch were in the "OFF" position. The modification had not yet been incorporated in the accident helicopter. As a result, the pilot would not have seen any abnormal indications on the caution and warning panel before and during takeoff and during the left yaw rotation. In addition, although the caution light modification provides a pilot with a visual indication of the yaw servo hydraulic switch position, the modification does not alert the pilot to reduced or no hydraulic pressure to the tail rotor hydraulic circuit.
- **Need for changes to the tail rotor flight controls of AS350-series helicopters with a dual hydraulic system to ensure pedal control hydraulic assistance and mitigate the possibility of pilot error during hydraulic system checks.** The design of the tail rotor hydraulic circuit of AS350-series helicopters does not ensure continuous pedal control hydraulic assistance and mitigate the possibility of pilot error during hydraulic systems checks. For example, a pilot checks the functionality of the yaw load compensator after a flight is completed, and this functional assessment depends on the pilot's ability to reliably discriminate among pedal forces to determine whether the yaw load compensator accumulator is pressurized. A solution to achieve these safety benefits could be to use the design philosophy of the main rotor flight control system (which includes dual-cylinder main rotor servo controls) and incorporate a dual-cylinder tail rotor servo control in the tail rotor hydraulic circuit. A dual-cylinder tail rotor servo control would consistently provide hydraulic assistance redundancy and would mitigate the possibility of pilot error during any hydraulic system check because the yaw load compensator and its associated check would no longer be necessary. Solutions other than a dual-cylinder tail rotor servo control might also achieve these safety benefits.
- **Lack of readily available information for helicopter operators and customers regarding safety equipment and systems that would enhance a helicopter's crashworthiness.** As previously stated, the FAA improved crashworthiness standards by issuing new fuel system crashworthiness requirements for helicopters certificated after November 1994. In addition, the FAA issued new occupant safety requirements for emergency landing conditions for helicopters certificated after December 1989. These new standards were not retroactive and thus did not apply to existing and newly manufactured helicopters with type certificates that were approved before the effective

dates of the regulations. The distinction between a helicopter's type certificate date and manufacture date relative to the improved crashworthiness requirements might not be clear to helicopter operators and customers; as a result, they might not be making fully informed purchasing and leasing decisions regarding a helicopter's crashworthiness. Guidelines identifying the equipment and systems that would meet the latest helicopter crashworthiness standards could result in an increased awareness about the availability of crash-resistant fuel systems and energy-absorbing seats and the lack of these safety features in many existing and newly manufactured helicopters.

- **Need for crash-resistant fuel systems for helicopters not covered by the November 1994 fuel system crashworthiness requirements.** Because the fuel systems on newly manufactured helicopters with type certificates approved before November 1994 were not subject to the fuel system crash resistance regulations, they might pose a fire hazard to occupants if the systems were breached during a crash that was otherwise survivable. In July 2015, the NTSB issued Safety Recommendation A-15-12 to the FAA to require, for all newly manufactured rotorcraft regardless of the design's original certification date, that the fuel systems meet the crashworthiness requirements of the regulations. The FAA responded that it started the rulemaking process by sending a tasking statement to the Aviation Rulemaking Advisory Committee's Rotorcraft Occupant Protection Working Group. The NTSB continues to monitor the FAA's progress in implementing the recommended action.
- **Lack of requirements to install, on smaller aircraft, flight recorder systems that protect recorded data from crash impact damage and postcrash fire damage.** The NTSB issued a series of recommendations to the FAA between 1999 and 2013 regarding the need for crash-resistant flight recorder systems on new and existing aircraft that were not already required to have such recorders. The FAA stated that rulemaking to mandate recorders on such aircraft was not a viable option because of significant costs and the limited ability to assess benefits. As a result, the FAA began promoting the voluntary equipage of onboard image recorders for these aircraft. Most smaller aircraft involved in the NTSB's investigations do not have a crash-resistant flight recorder. Although the NTSB has investigated accidents in which aircraft were voluntarily equipped with image recorders, the data were not recovered during some of these investigations because the recorders did not comply with the FAA's related TSO, which addresses crash resistance to protect recorded data from impact and postcrash fire damage. These situations have affected the NTSB's ability to fully identify the safety issues involved in accidents and the actions to prevent the accidents from recurring.

The National Transportation Safety Board determines that the probable cause of this accident was Airbus Helicopters' dual-hydraulic AS350 B3e helicopter's (1) preflight hydraulic check, which depleted hydraulic pressure in the tail rotor hydraulic circuit, and (2) lack of salient alerting to the pilot that hydraulic pressure was not restored before takeoff. Such alerting might have cued the pilot to his failure to reset the yaw servo hydraulic switch to its correct position during the preflight hydraulic check, which resulted in a lack of hydraulic boost to the pedal controls, high pedal forces, and a subsequent loss of control after takeoff. Contributing to the accident was the pilot's failure to perform a hover check after liftoff, which would have alerted him to the pedal control anomaly at an altitude that could have allowed him to safely land the helicopter. Contributing to the severity of the injuries was the helicopter's fuel system, which was not crash resistant and facilitated a fuel-fed postcrash fire.

As a result of this investigation, the NTSB makes safety recommendations to the FAA, Airbus Helicopters, the European Aviation Safety Agency, the Association of Critical Care Transport, the Association of Air Medical Services, and the Air Medical Operators Association. The NTSB also reiterates two safety recommendations to the FAA.

1. Accident Investigation and Analysis

1.1 The Accident

On July 3, 2015, about 1339 mountain daylight time (MDT), an Airbus Helicopters AS350 B3e helicopter, N390LG, registered to and operated by Air Methods Corporation, lifted off from the Summit Medical Center Heliport (91CO), Frisco, Colorado, and then crashed into a parking lot; the impact point was located 360 feet southwest of the ground-based helipad.[1] The pilot was fatally injured, and the two flight nurses were seriously injured. The helicopter was destroyed by impact forces and a postcrash fire. The flight was conducted under the provisions of 14 *Code of Federal Regulations* (*CFR*) Part 135 on a company flight plan. Visual meteorological conditions prevailed at the time of the accident.

According to Air Methods, the planned destination for the helicopter was Gypsum, Colorado, and the purpose of the flight was a public relations activity. About 0734, the pilot contacted the Air Methods operations control center to receive the flight release.[2] An audio recording with the Flight For Life Colorado communications center indicated that the pilot conducted a routine morning briefing about 0841 during which he relayed no problems with the weather or the helicopter and no anticipated safety issues or hazards.[3]

A surveillance video of the helipad at the Summit Medical Center ambulance bay showed the pilot preflighting the helicopter beginning about 1331. The pilot then entered the cockpit and performed routine duties before initiating the takeoff. The flight nurse in the right aft seat stated that the helicopter "had a rough takeoff with some unusual pitch" and began to make a counterclockwise turn that "sort of paused momentarily" before the helicopter continued climbing and turning.[4] The flight nurse also stated that, after a 360º turn, the pilot appeared to "attempt to gain some forward airspeed" but that, "after a very brief forward flight, [the helicopter] violently began spinning counterclockwise." He recalled that the pilot was "preoccupied with trying to maintain control of the aircraft" as the helicopter descended and impacted the ground. The flight lasted about 32 seconds.

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[1] All times in this report are MDT.

[2] Air Methods uses a computer system for verifying, among other things, that a pilot meets flight and rest requirements and a helicopter is airworthy. After this information is verified, the system provides a flight release. On the morning of the accident, the pilot had difficulty logging into the system, so he called the operations control center to obtain the flight release.

[3] According to its website (https://www.flightforlifecolorado.org/FLC/Home/, accessed February 2, 2017), Flight for Life Colorado provides critical-care transport across the Rocky Mountain region. Flight For Life Colorado helicopters are operated by Air Methods from five medical centers, including St. Anthony Summit Medical Center. Flight For Life Colorado provides flight tracking and mission support services. The organization provided the flight nurses for the flight on the day of the accident.

[4] As explained further in section 1.6.2, the helicopter was equipped with three medical crewmember seats. One flight nurse was seated in the left aft seat, and the other flight nurse was seated in the right aft seat. Due to the injuries sustained as a result of the accident (as discussed in sections 1.1.1 and 1.6.2.1), the flight nurse in the left aft seat was not interviewed as part of this investigation.

Surveillance videos capturing the liftoff showed the helicopter yaw to the left (as viewed from the back of the helicopter looking forward) and spin counterclockwise (as viewed from the top of the helicopter looking downward) several times before descending and impacting a recreational vehicle (RV) and the parking lot.[5] A witness estimated that the helicopter reached an altitude of about 100 feet before it started to descend. After impact, the helicopter rolled onto its right side as the landing gear (skids) collapsed. The helicopter came to rest on a magnetic heading of about 060º.

The video capturing the ground impact (from the camera in the medical center parking lot) showed fuel flowing from the wreckage and the onset of a postcrash fire 3 seconds after impact. The postcrash fire spread and consumed or severely damaged most of the helicopter wreckage, including the main fuselage and tailboom (as further explained in section 1.3). Table 1 lists events that the video captured regarding the helicopter's flight and impact with the ground, and figure 1 shows the main wreckage site.

Table 1. Events shown on surveillance video of accident and aftermath.

Time (in seconds)	Event
0.0	Full image of the helicopter was first visible; helicopter was descending.
0.7	Helicopter tailboom contacted the RV (at its hood).
0.9	Helicopter impacted the ground.
1.9	Helicopter came to rest.
3.7	Fuel was visible on the pavement near the helicopter's right side.
3.9	Fire was visible.
10.2	Movement inside the helicopter was first observed.
24.5 to 26.7	An occupant on the ground and underneath the left-side door panel lifted the door panel and flipped it toward the front of the helicopter. (This occupant was later identified as the flight nurse in the left aft seat.)
26.9 to 31.1	The occupant on the ground stood up and ran away from the helicopter while on fire.
59.9 to 67.9	Another occupant evacuated the helicopter from an opening on the left side and jumped to the ground. (This occupant was later identified as the flight nurse in the right aft seat.)
97.1 to 107.3	A bystander pulled an occupant from the cockpit area. This occupant then rolled away from the helicopter area, and the bystander used a fire extinguisher to put out the fire around and on the occupant. (This occupant was later identified as the pilot.)

[5] The National Transportation Safety Board (NTSB) reviewed four separate videos of the accident helicopter. These videos showed the helicopter from cameras (1) inside the ambulance bay, (2) on a light pole in the medical center parking lot, (3) at the employee entrance to the medical center, and (4) near the helipad.

Figure 1. Main wreckage site.

1.1.1 Injury Information

The pilot, age 64, sustained blunt force and thermal injuries, including second- and third-degree skin burns and thermal lung injuries. He succumbed to his injuries about 75 minutes after the accident occurred. The flight nurse in the left aft seat, age 45, sustained blunt force and thermal injuries, including 90% total body area partial- and full-thickness burns.[6] The flight nurse in the right aft seat, age 32, sustained blunt force injuries but no thermal injuries.[7]

1.1.2 Meteorological Information

The closest official weather station to the accident site was located at Copper Mountain, Colorado (Red Cliff Pass), which was 7 miles south-southwest of the accident site at an elevation

[6] A partial-thickness burn (also known as a second-degree burn) does not penetrate the entire skin, whereas a full-thickness burn (also known as a third-degree burn) does.

[7] The bystander who assisted the pilot received burns to his arms and face.

of 12,028 feet (about 3,000 feet above the 9,042-foot elevation of 91CO).[8] At 1335 (about 4 minutes before the accident), the Copper Mountain automated weather observing system (AWOS) reported the wind from 280º at 19 knots with gusts to 24 knots, 10 miles visibility, scattered clouds at 6,000 and 7,000 feet above ground level (agl), a broken ceiling at 12,000 feet agl, a temperature of 18º C (64º F), and a dew point temperature of -1º C (30º F).[9] At 1355 (about 16 minutes after the accident), the AWOS reported the wind from 290º at 20 knots with gusts to 27 knots; 10 miles visibility; scattered clouds at 6,000, 8,000, and 9,000 feet agl; a temperature of 19º C (66º F); and a dew point temperature of -2º C (28º F).

An unofficial remote automated weather station at Soda Creek, Colorado, was located 4 miles east of the accident site at an elevation of 9,578 feet. The remote automated weather station provided hourly observations. The 1256 observation (43 minutes before the accident) reported the wind from 313º at 11 mph (about 10 knots) with gusts to 20 mph (about 17 knots), a temperature of 73º F, a dew point temperature of 37º F, and a peak wind gust direction from 298º. The 1356 observation (17 minutes after the accident) reported the wind from 311º at 11 mph (about 10 knots) with gusts to 21 mph (about 18 knots), a temperature of 75º F, a dew point temperature of 32º F, and a peak wind gust direction from 284º.

Section 1.4.2.1 provides additional meteorological information.

1.2 Pilot Information

The pilot held an airline transport pilot certificate with a rotorcraft helicopter rating and a commercial pilot certificate with airplane single-engine land and helicopter instrument privileges. He was also type rated on the Aérospatiale AS355 helicopter (visual flight rules privileges only).[10]

The pilot was hired by Rocky Mountain Helicopters on December 11, 1999, and began working with Air Methods in 2002 when the company acquired Rocky Mountain Helicopters. At the time of the accident, he was a line pilot and a field safety representative at the Air Methods Frisco base. The pilot became qualified on the AS350 B3 in April 2004 and received differences training on the AS350 B3e in August 2014.[11] He held a Federal Aviation Administration (FAA) second-class medical certificate, dated January 12, 2015, with a limitation that required him to "wear corrective lenses, possess glasses" for near and intermediate vision.[12]

The pilot had accumulated more than 13,200 hours of total flight time, 5,231 hours of which were in the AS350 (all variants), including 1,228 hours in the AS350 B3 and 111 hours in the AS350 B3e. His most recent recurrent training and proficiency check occurred in

[8] All elevations in this report are expressed as mean sea level unless otherwise noted.

[9] The AWOS was not augmented by an official observer.

[10] Aérospatiale merged with Messerschmitt-Bölkow-Blohm to become Eurocopter, which was renamed Airbus Helicopters in January 2014. Airbus Helicopters is the type certificate holder for AS355-series helicopters.

[11] The AS350 B3e has a different engine than the AS350 B3. The AS350 B3e is equipped with a dual hydraulic system. The AS350 B3 is normally equipped with a single hydraulic system but has the option of being outfitted with a dual hydraulic system. For more information about the AS350 B3e engine and hydraulic system, see section 1.3.

[12] Section 1.2.2 discusses the results of the pilot's most recent medical certification examination.

March 2015.[13] A review of the pilot's employment records did not reveal any disciplinary actions, and interviews with colleagues who had flown with the pilot did not reveal any concerns. In addition, during a postaccident interview, the Air Methods chief pilot stated that the pilot's colleagues gave him "rave reviews" about his flying abilities and that "everyone always felt safe with him."

1.2.1 Preaccident Activities

The pilot was off duty from 0737 on June 26, 2015, to 0735 on the day of the accident. The pilot's wife stated that, on June 30, he did activities around the house and went to sleep about 2100. On July 1, the pilot awoke about 0600. His wife could not recall his specific activities that day but reported that he went to sleep about 2100 with no disruptions during the night. The pilot's wife could not recall the time that he awoke on July 2, but she recalled that he did not indicate feeling tired. His activities that day included preparing their RV for the drive from their home in Golden, Colorado, to Frisco that evening. The pilot's wife indicated they left Golden (separately) between 1730 and 1745 and that he arrived in Frisco about 1830. (She arrived about 15 minutes later.) The pilot's wife reported that he was "very happy" that evening and that they went to a friend's house from 2000 to 2100. She also reported that they went to sleep in their RV by 2200 and that there were no disruptions during the night.

On July 3, 2015, the pilot awoke about 0600 and went to the hospital (at the medical center) about 0630 to shower. The pilot's wife reported that he was a morning person and that he seemed happy and felt good. The pilot's cellular telephone activity (calls and texts) that day began at 0734, when he called the Air Methods operations control center, and additional activity occurred from 0828 to 0908, 1051 to 1129, and 1226 to 1250. His wife did not recall anything unusual when they spoke that day; she reported that he was "chipper" and that he mentioned that it was a nice day. She stated that there was nothing unusual about his scheduled duty day on the day of the accident and that he had worked the same schedule for the last 27 years.

The pilot's wife did not know if he took a nap before the accident flight, but she noted that he usually napped later in the day (about 1500). She stated that he had never mentioned any chronic fatigue and that he did not have any sleep issues. She characterized him as an "efficient sleeper" and stated that he felt good with 7 to 8 hours of sleep.

1.2.2 Medical and Pathological Information

As part of his most recent medical certification examination, the pilot reported using the prescription medications levothyroxine, allopurinol, and atorvastatin.[14] The aviation medical examiner identified no significant issues in the pilot's medical history or physical examination.

The Summit County Coroner's Office determined that the pilot's cause of death was blunt force injuries and that contributing to his death was an "inflammatory reaction involving the lungs

[13] The proficiency check was conducted in accordance with 14 *CFR* 135.293 "Initial and Recurrent Pilot Testing Requirements," and 135.299, "Pilot in Command: Line Checks: Routes and Airports."

[14] The pilot's medical records indicated that he used levothyroxine to treat hypothyroidism and that he used allopurinol and atorvastatin to lower uric acid and cholesterol, respectively.

related to inhalation of the products of the fire including thermal injuries." The coroner's office also determined that the manner of death was an accident. The autopsy report stated that "the cause of death is consistent with respiratory failure due to extensive injury to the musculoskeletal components compromising the mechanics of respiration." The report also noted that the pilot's lung function was "further compromised by the inhalation of the products of combustion."

Toxicology tests performed by the FAA's Civil Aerospace Medical Institute on specimens from the pilot tested negative for a wide range of drugs, including major drugs of abuse. The results were positive for etomidate, an anesthetic that, according to hospital records, was used in the efforts to resuscitate the pilot after the accident.

1.2.3 Analysis

The pilot was properly certificated and qualified in accordance with federal regulations. A review of the pilot's work schedule and activities before the accident as well as recorded communications of the pilot (with personnel at the Air Methods operational control center) indicated no evidence of fatigue. The pilot's medical conditions and the three medications that he was prescribed to treat these conditions—levothyroxine, allopurinol, and atorvastatin—were unlikely to have impaired the pilot's ability to safely control the helicopter. Thus, pilot fatigue and the pilot's medical conditions and prescribed medications were not factors in this accident.

1.3 Helicopter Information

1.3.1 General

The AS350 B3e main fuselage includes the main transmission, landing skids, engine, fuel tank, cabin, windows, and doors (a forward door and an aft door on the left side and a pilot's door and an aft door on the right side). The AS350 B3e tailboom, which is attached to the main fuselage rear structure, supports, among other things, the tail rotor, horizontal stabilizer, and vertical fin. Regarding the accident helicopter, the surveillance videos showed no evidence of an in-flight structural failure of the main fuselage or the tailboom.

The accident helicopter, serial number 7595, was manufactured in March 2013. Figure 2 shows the helicopter at the time of delivery to Air Methods.[15] At the time of the accident, the helicopter had a total time of about 487 flight hours. The helicopter was equipped with a Turbomeca Arriel 2D turboshaft engine, which had a total time of about 481 hours. (See section 1.3.2 for more information about the engine.) The helicopter's weight at the time of the accident was about 4,717 pounds, which was based on the operating conditions that day and included the weights of the occupants, fuel, and medical equipment.

[15] Air Methods records showed a registration date for N390LG of September 20, 2013.

Figure 2. N390LG upon delivery to Air Methods.

According to Air Methods, the accident helicopter was maintained under an FAA-approved aircraft inspection program. Helicopter logbook records showed the following maintenance events during the days before the accident:

- On June 30, 2015, a 200-hour/90-day inspection of various equipment installed on the helicopter was performed.
- On July 1, 2015, 30-hour inspections of the engine freewheel assembly and the tail rotor blades were performed, and a 300-hour/180-day inspection was performed during which the engine oil and filter were changed.
- On July 2, 2015, a 15-hour/7-day inspection and a 25-hour inspection of the engine and the vehicle engine monitoring display were performed, a 180-day inspection and a 500-hour/12-month inspection of various equipment installed on the helicopter were performed, and a 500-hour inspection and lubrication of the tail rotor drive shaft hanger bearings were performed. This maintenance was performed before the first flight of the day. The helicopter flew about 4 hours in between the completion of this maintenance and the accident flight.

1.3.2 Engine Information

The AS350 B3e helicopter is equipped with a Turbomeca Arriel 2D turboshaft engine, which has a single-stage axial flow compressor, a single-stage centrifugal flow compressor, an annular combustor, a single-stage turbine rotor that drives the compressors, and a free turbine (also known as power turbine) rotor.[16] A reduction gearbox (connected to the free turbine rotor) provides final drive to the power transmission shaft.

The engine was found at the main wreckage site on its right side and attached to the engine deck via the rear engine mounts. The engine's external surfaces showed evidence of thermal damage. The leading edges of the axial flow compressor blades showed evidence of hard-body impact damage.[17] All of the free turbine blade roots had overload fractures that were consistent with turbine blade shedding. The reduction gearbox was located, removed, and inspected, and the input pinion index mark was found offset in the tightening (torque) direction by 0.04 inch.

The helicopter was equipped with a Turbomeca/Thales digital engine control unit, serial number unknown. The unit's two sets of circuit boards sustained extensive high-temperature thermal damage, and the unit's nonvolatile memory (NVM) chips, which can retain electronic engine log records, yielded no usable data about the accident.

1.3.2.1 Analysis

The impact damage on the axial flow compressor blade leading edges was likely caused by the engine continuing to run and ingest portions of the aluminum engine intake duct during the impact sequence. The free turbine blade shedding was consistent with a free turbine overspeed (in excess of 150% rpm). The overspeed was likely due to the sudden decoupling of the engine from the main transmission at ground impact while the engine was still running. The engine reduction gearbox input pinion index mark was consistent with the engine producing power when the main rotor blades struck the RV during the helicopter's descent. Thus, no evidence indicated any anomalies that would have precluded normal operation of the engine before ground impact.

1.3.3 Rotor Systems

The AS350 B3e has a three-bladed main rotor system that provides lift and thrust and a two-bladed tail rotor system that provides thrust to counteract the main rotor torque effect and control yaw.[18] Both rotors turn at a constant rpm. A dual hydraulic system, which consists of an upper and a lower hydraulic system, provides hydraulic assistance to the main rotor flight controls.[19] The lower hydraulic system also provides hydraulic assistance to the tail rotor flight controls. The main and tail rotor systems and the dual hydraulic system are discussed further in the sections that follow.

[16] The AS350 B3e is a marketing designation and received its type design certification under the AS350 B3 type certificate. The original AS350 B3 helicopter was type certificated with a Turbomeca Arriel 2B engine and later an Arriel 2B1 engine.

[17] Hard-body impact damage is characterized by a serrated appearance and deep cuts or tears to a blade's leading and trailing edges. Such damage can result from ingestion of metal parts, concrete, asphalt, or rocks.

[18] The main rotor blades rotate in a clockwise direction as viewed from above the main rotor disc.

[19] The original AS350 B3 helicopter was type certificated with a single hydraulic system.

1.3.3.1 Main Rotor

Engine power is transferred to the main rotor via an engine-to-transmission drive shaft and a main gearbox. The three main rotor blades and their associated parts are assigned a color (blue, red, or yellow) for identification purposes. The three main rotor blades attach to a Starflex rotor head via blade sleeves (two sleeves per blade).

The accident helicopter’s three main rotor blades were found attached to the main rotor head. All three blades showed thermal damage and could not be identified by their assigned color. The main rotor blade spars showed significant damage that was consistent with high rotational energy. The Starflex and blade sleeves showed thermal damage and fractures that were consistent with impact with high rotational energy. The main rotor shaft remained attached to the Starflex. When the transmission input pinion was rotated manually, a corresponding rotation was observed on the Starflex, consistent with continuity of drive through the main transmission. The pitch change rods remained attached between the rotating swashplate and each pitch change horn.

1.3.3.2 Tail Rotor

Engine power is transferred to the tail rotor via a two-section tail rotor drive shaft and a tail gearbox. The tail rotor hub, which is connected to the tail gearbox output shaft, drives the tail rotor. The two tail rotor blades share a composite spar. Tail rotor thrust is varied by adjusting the pitch angle of both tail rotor blades equally and simultaneously. Tail rotor blade pitch is changed via pitch change links. Each set of tail rotor blades and pitch change links is assigned a color (red or yellow) for identification purposes.

Both tail rotor blades were found at the accident site. The red tail rotor blade was fractured at its root end (but remained partially attached to the tail rotor hub) and showed evidence of thermal damage. An outboard portion of the red blade, which was found away from the main wreckage, did not exhibit thermal damage. The yellow tail rotor blade was fractured at its root end and showed evidence of thermal damage.

Both tail rotor pitch change links were fractured near the pitch change assembly ends and exhibited thermal damage. Part of the yellow pitch change link showed no evidence of thermal damage but had fracture surface signatures consistent with overload from ground impact. Most of the aluminum section of the tail rotor drive shaft was consumed by the postcrash fire.

The tail gearbox was found with portions of the tailboom structure attached, which were fractured and showed evidence of thermal damage. The aft end of the tail rotor drive shaft remained attached to the tail gearbox input flange via a flexible coupling and attaching hardware. The flexible coupling did not exhibit high rotational energy damage, such as fracturing and splaying of the coupling laminates.

1.3.3.3 Analysis

The main rotor blades and Starflex showed no signatures consistent with abnormal operation of the main rotor system before ground impact.[20] In addition, one of the surveillance videos showed the helicopter lifting off the helipad and continuing powered lift while the yaw rate developed and increased, which was consistent with power to the main rotor system before impact.

Because of the impact damage and postcrash fire, evidence of tail rotor drive continuity and power at the time of liftoff, when the yaw rate occurred, could not be determined solely from the wreckage examination. However, a loss of tail rotor drive would result in an immediate and significant loss of tail rotor thrust, and the yaw rate observed in the surveillance video (as discussed further in section 1.4.1) would likely have been more than three times higher than that observed if the left yaw had been caused by a loss of tail rotor drive.[21] Thus, video evidence showed that the tail rotor drive system was likely providing power to the tail rotor when the helicopter was lifting off the ground. In addition, the lack of high rotational energy signatures on the remaining aft portion components of the tail rotor drive system (the remaining flexible couplings) was likely due to the severing of the system when the tailboom first impacted the RV, which occurred immediately before the tail rotor impacted the ground.

1.3.4 Flight Control System

The helicopter flight control system includes collective and cyclic sticks and left and right pedals. The collective stick increases and decreases the total thrust produced by the main rotor by increasing or decreasing main rotor pitch blade angle equally and simultaneously. The cyclic stick controls helicopter movements in the pitch and roll axes. The cyclic stick is moved forward, aft, to the left, or to the right to vary the pitch of the main rotor blades at different points throughout each revolution of the main rotor and tilt the rotor disk in a particular direction, resulting in the helicopter moving in that direction.

Cyclic and collective control inputs are transmitted to a stationary swashplate through a series of push-pull tubes and bellcranks. The main rotor cyclic and collective controls are hydraulically assisted via three dual-cylinder main rotor servo controls: fore/aft, right roll, and left roll. At the time of the accident, only the right-side pilot flight controls were installed in the helicopter; the left-side flight controls were removed as part of an approved helicopter air ambulance modification.

The pedals increase and decrease the total thrust produced by the tail rotor by increasing or decreasing the pitch angle of both tail rotor blades equally and simultaneously, providing a

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[20] Even though a portion of the red tail rotor blade was found away from the wreckage, it is unlikely that the blade failed. A tail rotor blade failure would have resulted in an imbalance in the tail rotor, leading to anomalous vibrations that the helicopter occupants would have felt. The flight nurse in the right aft seat did not recall any such vibrations. Thus, the evidence indicated that the blade came off the tail rotor during ground impact.

[21] Simulations performed to estimate left yaw rates, as discussed further in section 1.4.2, resulted in a left yaw rate of 125° per second for a near-neutral pedal position. The surveillance video, as discussed further in section 1.4.1, showed that the accident helicopter had an average left yaw rate of 30° per second at takeoff. Because a loss of tail rotor drive would result in a left yaw rate that would be greater than that for a neutral pedal position, the left yaw rate with a loss of tail rotor drive would likely have been more than three times higher than the left yaw rate observed in the surveillance video.

means to counteract the torque from the main rotor and allowing for directional (yaw) control of the helicopter. For example, as the main rotor torque increases, a corresponding right pedal control input is required to increase tail rotor thrust to maintain the helicopter's heading, thereby controlling the left yaw imparted by the main rotor, which turns in a clockwise direction.

The AS350 B3e helicopter has two pedal mounts, one for the front left seat and one for the front right seat. For the accident helicopter, a pedal set comprising two pedals (left and right) was installed at the pedal mount location for the front right seat. The directional control lateral push-pull tube is connected to, and provides coordinated movement between, both pedal mounts. The directional control lateral push-pull tube is located underneath the cockpit floorboard and is routed through a cutout in the floor structure.

Pedal control inputs are transmitted to a single-cylinder tail rotor servo control through a series of control linkages, bellcranks, and a flexible ball control cable.[22] A yaw load compensator connects to the tail rotor servo control output piston via the compensator connecting link, which actuates a push-pull tube connected to the pitch change bellcrank mounted to the tail gearbox. The yaw load compensator has an accumulator that contains a rubber bladder that is charged with nitrogen gas to about 218 pounds per square inch.

As previously stated, the AS350 B3e is equipped with an upper and a lower hydraulic system.[23] The dual hydraulic setup provides hydraulic assistance redundancy to the main rotor servo controls in case one of the hydraulic systems were to fail.[24] The tail rotor servo control, yaw load compensator, and its accumulator are powered only by the lower hydraulic system. The yaw load compensator and its accumulator comprise a closed-loop system that would provide continuous hydraulic power assistance to the pedal controls in the event of a depressurization of the lower hydraulic system.[25] (The yaw load compensator is biased toward the right pedal because a right pedal input is needed to counteract the main rotor torque effect.) Figure 3 shows the hydraulic system configuration of the accident helicopter.

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[22] The tail rotor servo control is also referred to as the yaw servo control.

[23] Each hydraulic system contains its own pump, filter, regulator valve, and reservoir. A gear-driven hydraulic pump provides hydraulic pressure to the upper hydraulic system; a belt-driven hydraulic pump provides hydraulic pressure to the lower hydraulic system.

[24] For example, if one of the two hydraulic systems failed because of a hydraulic pump malfunction, the other system would provide hydraulic assistance redundancy for the main rotor flight controls.

[25] For hydraulically boosted flight controls, 14 *CFR* 27.695, "Power Boost and Power-Operated Control System," requires that an alternate system be available to allow continued safe flight and landing in the event of a failure of a portion of the hydraulic system.

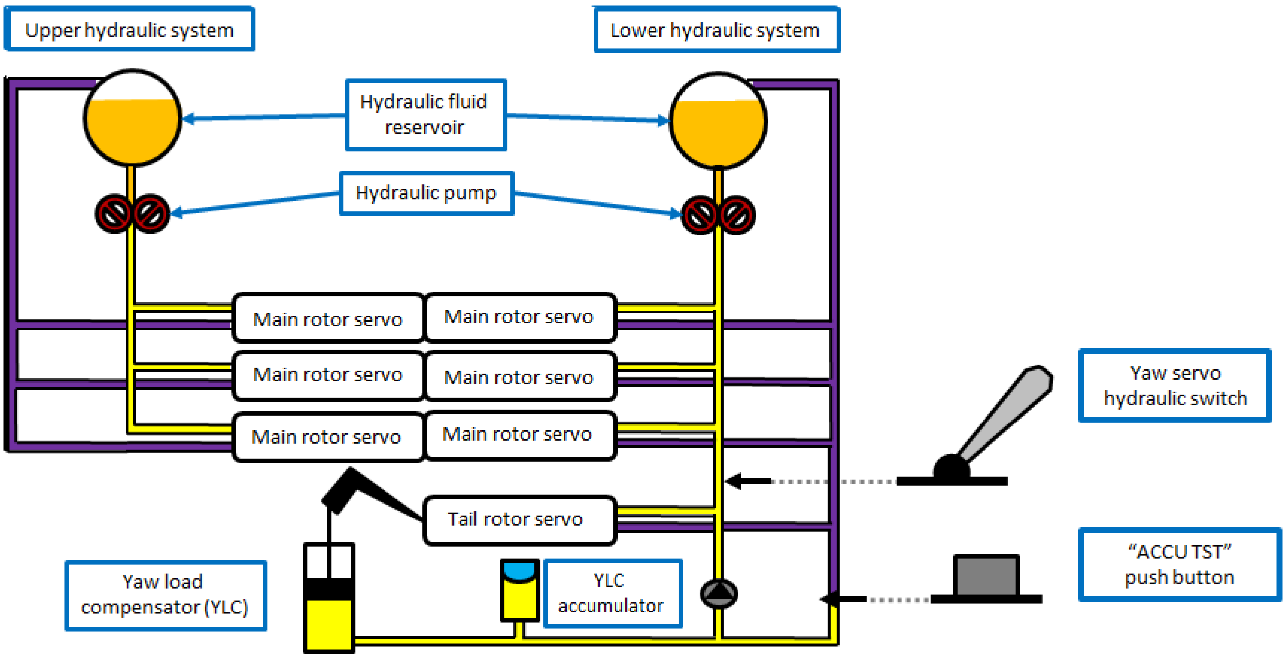


Figure 3. AS350 B3e dual hydraulic system.

The hydraulic isolation electrovalve, installed on the transmission deck, provides a means to isolate the tail rotor hydraulic circuit from the lower hydraulic system in the event of a tail rotor servo control malfunction. Actuation of the hydraulic isolation electrovalve is controlled by a yaw servo hydraulic switch located on a control block installed at the forward end of the collective stick (see figure 4 in section 1.3.5.1). During normal operation, the hydraulic isolation electrovalve is in the open position, and the yaw servo hydraulic switch is on.

The yaw load compensator assembly contains an accumulator test electrovalve that allows hydraulic pressure to discharge from the yaw load compensator and accumulator when the "ACCU TST" push button, located on the cockpit center console, is depressed. Operating procedures for the AS350 B3e at the time of the accident indicated that the "ACCU TST" push button should be depressed during a ground check of the yaw load compensator accumulator (see section 1.3.5.1) or as part of emergency procedures for a tail rotor control failure. During normal operations, the accumulator test electrovalve is in the closed position, and the "ACCU TST" push button is raised.

The cyclic and collective sticks were found in their installed positions. The collective stick was found near its lowest position, and the cyclic stick was found slightly bent to the left. The push-pull tubes and bellcranks for the cyclic and collective were connected at their forward ends and showed evidence of thermal damage. All three main rotor servo controls remained attached at both ends to the main transmission housing and the stationary swashplate. The input rod ends remained attached on all three main rotor servo controls, but the input rods were fractured and showed evidence of thermal damage.

The cockpit instruments could not be reliably read because of thermal damage. The control block at the forward end of the collective stick was partially consumed by the postcrash fire.

The directional control lateral push-pull tube was found in its installed position. Continuity of control was confirmed between the left and right pedal mounts. Both pedals were found in their installed position with the left pedal near its forward stop. The push-pull tube for the right pedal was fractured and showed evidence of thermal damage. The remaining pedal controls were continuous back to the flexible ball cable.

The directional control lateral push-pull tube was found with a dent in the upward direction near the cutout in the floor structure. When the left pedal was manually moved to its fully forward position, the dent on the push-pull tube moved laterally to the right side of the helicopter. When the right pedal was manually moved to its fully forward position, the dent on the push-pull tube moved laterally to the left side of the helicopter. In addition, when the right pedal was near its full forward position, the dent on the push-pull tube lined up with the cutout in the floor structure.

The aft portion of the tail rotor flight control system was mostly consumed by the postcrash fire. The tail rotor servo control and yaw load compensator assembly (including the yaw load compensator and its accumulator and the accumulator test electrovalve) were found unattached within the main wreckage. The hydraulic isolation electrovalve was not found in the wreckage. The tail rotor servo control rod end was not attached to the tailboom structure, but the attaching hardware and resolidified melted aluminum were found within the rod end. Hydraulic lines remained attached to the yaw load compensator assembly and exhibited thermal damage. Attaching hardware was observed where the assembly body and the compensator lever were mounted to the tailboom structure. The yaw servo hydraulic switch was found in the forward ("ON") position.[26] The "ACCU TST" push button was partially consumed by the postcrash fire. Most of the lower hydraulic system was consumed by the postcrash fire.

X-ray scans of the remaining collective stick control block and the "ACCU TST" push button were performed at the NTSB's Materials Laboratory in Washington, DC. The position of collective stick control block switches (including the yaw servo hydraulic switch) and the "ACCU TST" push button switch could not be determined because of the damage to the components resulting from the accident.

Computerized tomography scans of the tail rotor servo control and yaw load compensator were performed at an outside facility. The scans showed that the tail rotor servo control manual lock pin was engaged. (The spring-loaded manual lock pin engages when hydraulic pressure is removed from the servo control.) The yaw load compensator accumulator showed pitting on the inner walls. Debris consistent with a thermally decomposed rubber bladder was observed within the accumulator. The compensator piston appeared to be in its normal position within the body of the compensator.

1.3.4.1 Analysis

The main rotor flight control system was found fractured in multiple locations and was partially consumed by the postcrash fire. The wreckage that remained did not reveal abnormal damage patterns or disconnects to the main rotor flight control system. In addition, a surveillance

[26] Section 1.5.3 provides a possible explanation regarding why the yaw servo hydraulic switch was found in this position.

video showed the helicopter lifting off the helipad with no evidence of abnormal controllability of the main rotor flight controls. Thus, the main rotor flight control system exhibited no evidence of malfunction before ground impact.

The forward portion of the tail rotor flight control system did not show evidence of a disconnect or a physical restriction when operated manually. The tail rotor servo and yaw load compensator rod end attachment points also did not show evidence of a disconnect. The dent in the directional control lateral push-pull tube was consistent with the right pedal in its fully forward position at the time of ground impact.[27] The engaged position of the tail rotor servo control manual lock pin indicated that manual control of the tail rotor pitch change mechanism would still be possible if the tail rotor servo control experienced a loss of hydraulic pressure.

Because the hydraulic isolation electrovalve was not recovered in the wreckage (it had likely been destroyed by the postcrash fire), the NTSB could not determine if the valve had malfunctioned. However, even with a hydraulic isolation electrovalve malfunction, a correctly configured tail rotor hydraulic circuit, with a functioning yaw load compensator, could provide partial hydraulic assistance to the pedals.[28] Although the yaw servo hydraulic switch was found in the forward position, the position of the internal switch mechanism at the time of impact could not be determined due to thermal damage. In addition, because of damage from impact forces and the postcrash fire, the internal switch position of the "ACCU TST" push button at the time of impact could not be determined.

Given the information in this section as well as sections 1.3.2.1 and 1.3.3.3, the helicopter was properly certificated, equipped, and maintained in accordance with federal regulations. None of the available evidence indicated any preimpact structural, engine, or system failures.

1.3.5 Additional Helicopter Information

1.3.5.1 Yaw Servo Hydraulic Check

Airbus Helicopters procedures required actuation of the yaw servo hydraulic switch and the "ACCU TST" push button (shown in figure 4) during the yaw servo hydraulic check, which, at the time of the accident, was part of the preflight run-up check. The purpose of the yaw servo hydraulic check was to ensure the functionality of the yaw load compensator accumulator by isolating hydraulic pressure to the tail rotor circuit and checking the pedal forces. The Air Methods AS350 B3e Normal Procedures checklist, dated August 2014, indicated that the hydraulic check occurred during the "Starting Engines" procedures, and the following steps for the yaw servo

[27] Section 1.5.3 provides a possible explanation regarding why the right pedal was found in this position.

[28] The NTSB asked Airbus Helicopters for a procurement history of hydraulic isolation electrovalves for AS350-series helicopters from January 1, 2008, to July 15, 2016, to determine if this part had previously failed. Airbus Helicopters indicated that it had received no orders for the electrovalve since 2008. In addition, Air Methods stated that it had no recent history of orders for the electrovalve and reported no reliability issues with the part.

hydraulic check were detailed in an expanded checklist for AS350 B3 helicopters with a dual hydraulic system:[29]

a. Yaw servo hydraulic switch (collective grip)—OFF, pedal forces should remain low (yaw load compensator effect).

b. [HYD TEST] or [ACCU TST] – DEPRESS, forces felt on pedals.

c. [HYD TEST] or [ACCU TST] – RESET IN OFF position (out).

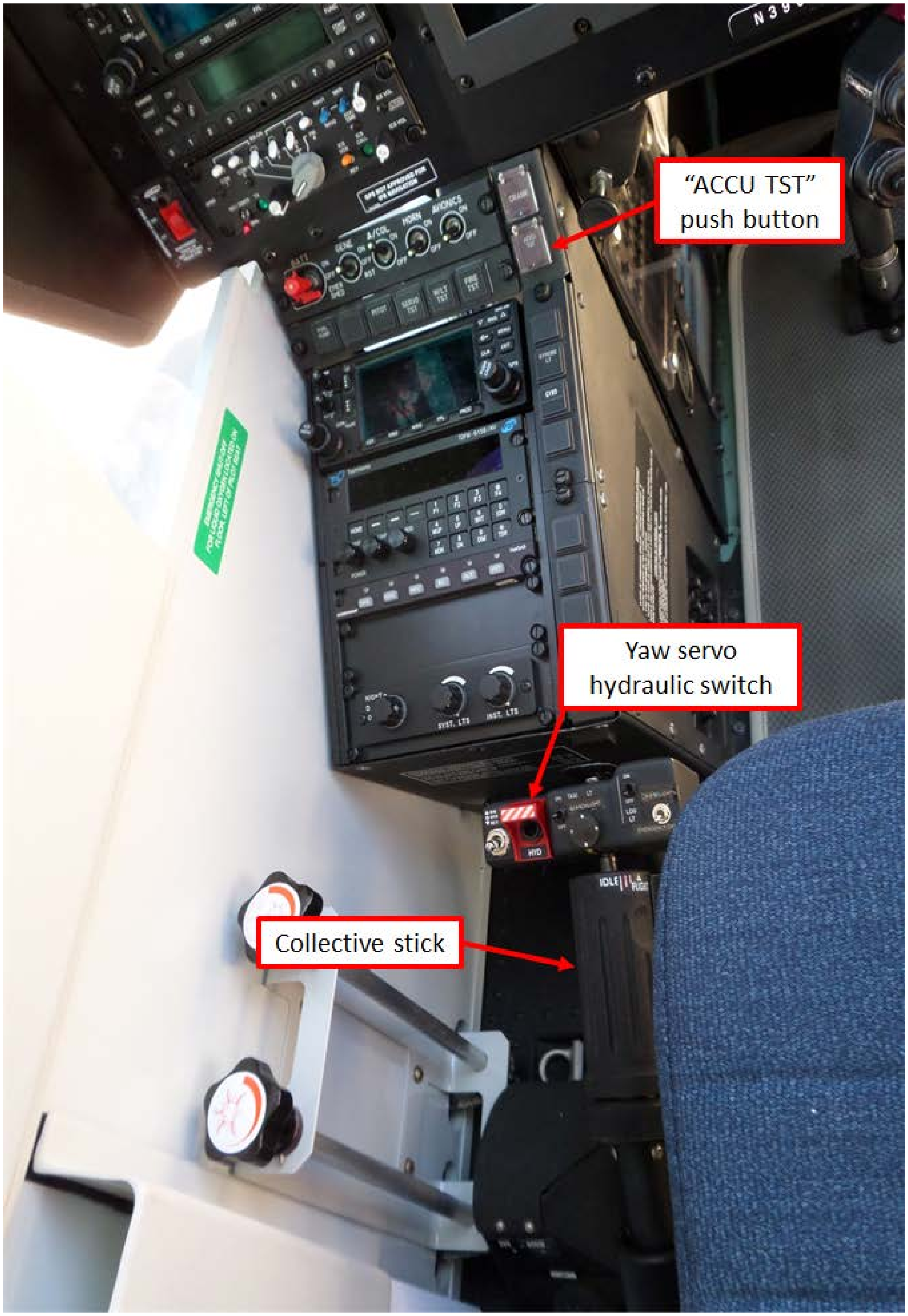
d. Yaw Servo Hydraulic Switch (collective grip) – ON, check no forces are felt on yaw pedals (boosted).

An Air Methods pilot who flew with the accident pilot stated that the accident pilot always used this checklist, and a company flight instructor observed the accident pilot using the checklist during training. Another Air Methods pilot thought that company pilots were required to use this expanded checklist. Air Methods personnel stated that hydraulic system training did not include information about the helicopter's response if the yaw servo hydraulic check was not properly completed.[30]

After the accident, Airbus Helicopters and the FAA changed the hydraulic check to a postflight check. Section 1.3.5.4 provides information about this change.

[29] The "HYD TEST" and "ACCU TST" push buttons, as noted in steps b and c of the procedure, perform the same function. For the AS350 B3e variant, the push button is labeled "ACCU TST."

[30] Section 1.4.3.2 discusses the pedal loads that the pilot would feel during the yaw servo hydraulic check, which would provide the pilot with an indication of whether the check was correctly performed.



Source: Air Methods.

Figure 4. Yaw servo hydraulic switch and "ACCU TST" push button.

Note: This photograph shows the cockpit of the AS350 B3e helicopter involved in the Frisco accident.

1.3.5.2 Takeoff Procedures

Air Methods and Airbus Helicopters procedures stated that the AS350 B3e helicopter should lift off to a hover as a part of the takeoff procedures. Specifically, Air Methods Pilot Training Curriculum Program, Annex 1, "AS350 Curriculum Segment," section 4, "Takeoffs," stated in part the following under the headings "From the Surface" and "Initial Conditions":

> 1. In an AS350 Helicopter
>
> 2. On the ground, preferably into the wind
>
> 3. Before Takeoff Check: Complete
>
> 4. Hover Power Check: Ensure 10% margin below maximum T/O [takeoff] power or HOGE [hover out of ground effect] is available: Complete
>
> 5. Area: Clear

Also, Airbus Helicopters AS350 B3e *Aircraft Flight Manual*, chapter 4 "Normal Procedures," section 4.4, "Takeoff," stated in part the following under the heading "Takeoff Check and Procedure":

> - Gradually increase collective pitch to hover at 5 ft. (1.5 m). Check engine and mechanical control instruments, no warning light.
>
> - Increase airspeed with HIGE [hover in ground effect] power until IAS [indicated airspeed] = 40 kt (74 km/h), then begin to climb so as to clear 40 ft (12 m) at IAS = 50 kt (93 km/h).

During postaccident interviews, Air Methods personnel stated that pilots were trained to lift off to a hover and perform a power check before takeoff. Company personnel also stated that it was common practice to slightly increase the collective to lift the helicopter about 3 to 5 feet above the ground and perform a check of systems. Section 1.5.4 discusses the pilot's failure to perform a hover check during the accident flight.

1.3.5.3 Previous Dual-Hydraulic AS350-Series Helicopter Events Involving Loss of Yaw Control

On April 9, 2014, an Airbus Helicopters AS350 B3e crashed into a hospital rooftop in Albuquerque, New Mexico, after departing from the hospital's heliport. The helicopter was operating under the provisions of 14 *CFR* Part 91 as a local positioning flight. The pilot and two medical technicians received minor injuries, and the helicopter was substantially damaged.[31] The pilot reported that he completed the preflight hydraulic check and did not note anything abnormal

[31] The brief report for each event summarized in this accident report can be searched by case number from the NTSB's Aviation Accident Database web page, and each investigation's public docket can be accessed from the NTSB's Accident Dockets web page. All NTSB documents are accessible from the NTSB's home page (www.ntsb.gov). For more information about this accident, see case number CEN14FA193.

with the pedal movement. During the takeoff, the pilot expected to make a slight left turn to clear the heliport platform and hospital for departure, but the helicopter kept turning. The pilot attempted to apply right pedal to stop the turn but reported that the pedals felt jammed or locked in the neutral position. The helicopter began spinning to the left.

Although the yaw servo hydraulic switch was found in the "ON" position, the switch's position at takeoff could not be determined because of the lack of an onboard image recorder. The NTSB determined that the probable cause of the accident was "the pilot's loss of yaw control during takeoff due to the absence of hydraulic boost to the tail rotor pedals for reasons that could not be determined based on the available information." A finding in the accident was "the lack of a caution indicator to alert the pilot of the lower hydraulic system configuration."

During the investigation of the Albuquerque accident, the NTSB learned about a 2009 event involving a Eurocopter AS350 B3 helicopter with a dual hydraulic system that was operated by the US Customs and Border Protection. According to Airbus Helicopters and the FAA, the helicopter experienced a loss of yaw control because the yaw servo hydraulic switch was not reset to the "ON" position during the preflight hydraulic check.[32]

In addition, the NTSB investigated a June 26, 2014, incident involving an Airbus Helicopters AS350 B3 helicopter, N808LF, at the Draughon-Miller Central Texas Regional Airport, Temple, Texas. The helicopter was operated by Air Methods under the provisions of 14 *CFR* Part 91 as a positioning flight. The pilot reported that, immediately after takeoff, the helicopter started to yaw to the left. He indicated that the pedals were locked in the neutral position and felt jammed and that he attempted to correct the rotation but was unable to do so. The pilot then executed a precautionary hovering autorotation. The pilot and two crewmembers were not injured, and the helicopter received minor damage.

A postincident examination of the helicopter found no anomalies with its tail rotor and hydraulic systems, but the yaw servo hydraulic switch was found in its "OFF" position. The NTSB determined that the probable cause of this incident was "the pilot's failure to reposition the yaw servo hydraulic switch to the 'on' position during the pretakeoff hydraulic system check, which resulted in a complete lack of hydraulic boost to the tail rotor system and increased the load required to move the control pedals and led to the pilot's subsequent inability to manipulate the control pedals and his loss of yaw control."[33]

1.3.5.4 Safety Information to Prevent Lack of Hydraulic Boost to Pedals

On August 21, 2014, Airbus Helicopters issued Safety Information Notice No. 2776-S-29 to provide information about the preflight hydraulic check for AS350 B3 helicopters with a dual hydraulic system.[34] In the notice, Airbus Helicopters stated that it became aware of "at least two

[32] The NTSB should have been notified about this event when it occurred but was not notified for undetermined reasons.

[33] For more information about this incident, see case number CEN14IA329.

[34] At the time of the accident, Airbus Helicopters safety information notices and related documents were sent to the engineering department at Air Methods, and a department staff member reviewed each document to determine the relevant departments within the company that needed to receive the document. There was no formal process for

events possibly involving pilots taking off without any hydraulic assistance on the tail rotor." Airbus Helicopters also stated that, on the basis of the available information at that time, it appeared that the pilots, after verifying proper operation of the "HYD TEST" or the "ACCU TST" push button and associated valve, most likely omitted the step to return the yaw servo hydraulic switch to the "ON" position, which would have restored hydraulic system pressure to the tail rotor servo control and yaw load compensator accumulator. Airbus Helicopters indicated that "omission of this step will result in a complete lack of hydraulic boost to the tail rotor system," which "could be perceived by the pilot as a tail rotor control failure (jamming) due to the increased load required to move the pedals." Airbus Helicopters further indicated that this situation, if not quickly identified and corrected, could lead to a loss of control of the helicopter. The notice then explained in detail what each step of the preflight hydraulic check accomplished and how each step affected the tail rotor hydraulic circuit.

On February 25, 2015, Airbus Helicopters released Service Bulletin (SB) No. AS350-67.00.64 to provide information about the "HYDR" test indication for dual-hydraulic servo controls. The SB summary instructed AS350 B3 helicopter operators to do the following:

> Modify the 'HYDR' test indication on helicopters equipped with the double hydraulic system by:
>
> - Indicating to the pilot that the hydraulic switch on the collective grip is [incorrectly] set to 'OFF'.
>
> - Adding a second indicator light on the caution and warning panel to indicate the status of the two [hydraulic] systems.

The two caution indicator lights associated with this modification were labeled "HYD1" and "HYD2." Illumination of either of these lights would indicate a loss of hydraulic pressure to the upper or lower hydraulic system, respectively.[35] The "HYD2" light would also flash when the yaw servo hydraulic switch was set to the "OFF" position.[36] After issuing the SB, Airbus Helicopters offered kits so that dual-hydraulic AS350 B3 helicopter operators could incorporate this modification. The lights were not installed on the accident helicopter because Air Methods did not begin incorporating the modification on its dual-hydraulic AS350-series helicopters until after

distributing these documents to pilots. Air Methods personnel stated that, after the accident, the company began distributing Airbus Helicopters safety information notices and related documents to the entire Air Methods management team. In addition, a committee of company aviation compliance personnel and assistant chief pilots review the documents to determine the importance of the information and the necessary actions.

[35] At the time of this SB, AS350-series helicopters had three indicator lights on the caution and warning panel (including a "HYD" light) to alert a pilot of a loss of hydraulic pressure to the upper or lower hydraulic system.

[36] On November 4, 2016, the European Aviation Safety Agency (EASA) issued Airworthiness Directive (AD) 2016-0220, which required operators of AS350 B3 helicopters with a dual hydraulic system, within 12 months of the effective date of the AD (November 18, 2016), to modify their helicopters in accordance with the instructions in the SB.

the accident.[37] According to Air Methods, the SB was not labeled “mandatory,” and all nonmandatory SBs underwent a company risk assessment before being implemented. The risk assessment for this SB had not been performed at the time of the accident.

On August 26, 2015, Airbus Helicopters issued SB No. AS350-67.00.66 to modify the hydraulic check procedure for the yaw load compensator in the AS350 B3 *Aircraft Flight Manual*. The SB affected AS350 B3 helicopters equipped with either a single or a dual hydraulic system. For AS350 B3 helicopters with a dual hydraulic system, including the AS350 B3e variant, the preflight run-up check was modified to remove the yaw servo hydraulic check in its entirety, and a procedure to perform this check was added to the engine and rotor shutdown postflight procedures.[38] The postflight check, titled “Yaw Load Compensator Check,” requires a pilot, during rotor shutdown, to observe the right pedal moving forward without pilot input or verify that the right pedal can be moved forward with low force. The pilot then presses the “ACCU TST” push button for 2 seconds, which moves the button to its “ON” position. After the “ACCU TST” push button is returned to its “OFF” position, the pilot moves the pedals to their neutral position and confirms this position. The SB provided the revised pages to be inserted into the flight manual.[39] On October 22, 2015, Airbus Helicopters issued revision 1 of the SB “to make improvements in the appended pages.”

On October 28, 2015, the FAA issued emergency AD 2015-22-52. The FAA indicated that the actions in the AD were prompted by two accidents (Frisco and Albuquerque) and one incident (Temple, Texas) involving AS350 B3 helicopters in which a loss of tail rotor control occurred during takeoff. The AD prohibited performing a check of the yaw load compensator during preflight procedures and instead required that this check be performed during postflight procedures. The AD also required that the yaw servo hydraulic switch be in the “ON” position before takeoff. The AD indicated that these actions were intended to prevent a takeoff without hydraulic pressure in the tail rotor hydraulic circuit, a loss of tail rotor flight control, and a subsequent loss of control of the helicopter. The AD affected all AS350 B3 helicopters with a dual hydraulic system installed, including the AS350 B3e variant, and became effective upon receipt.

A subsequent emergency AD, 2015-22-53, issued on October 30, 2015, superseded emergency AD 2015-22-52 to clarify the requirements of the AD. The FAA published a final rule regarding AD 2015-22-53 (80 *Federal Register* 74982) on December 1, 2015 (NARA 2015).[40]

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[37] Air Methods elevated the priority of this SB after the Frisco accident and began efforts to comply with the SB 5 days after the accident. In January 2017, Air Methods indicated that, as of December 2015, it had complied with the SB for all of its AS350-series helicopters with a dual hydraulic system.

[38] Airbus Helicopters performed an analysis (the official results of which are not known by the NTSB) that considered the probability of taking off without hydraulic boost to the pedals versus the probability of taking off with an undetected failure of a yaw load compensator and a failure of the tail rotor servo control. (Airbus Helicopters had no reports of the latter situation occurring.)

[39] On August 26, 2015, EASA issued AD 2015-0178, which required operators of AS350 B3 helicopters with a dual hydraulic system, within 7 days of the effective date of the AD (August 31, 2015), to incorporate the new procedure into the normal procedures section of the applicable flight manual and inform flight crews of this change.

[40] FAA emergency AD 2015-22-53 was sent to all known US owners and operators of AS350 B3 helicopters with a dual hydraulic system. FAA AD 2015-22-53 became effective on December 16, 2015, to all persons except those already covered by emergency AD 2015-22-53.

1.4 Tests and Research

1.4.1 Video Study

The video camera located in the hospital's ambulance bay captured the first 8 seconds of the helicopter's flight. The video from this camera was used to estimate the helicopter's climb rate after takeoff. Two sets of data were considered—one comprising the last 5.4 seconds of the 8-second interval, and the other comprising the last 2.9 seconds of the interval—in estimating the elevation of the helicopter above the ground.[41] The video from this camera showed that the helicopter's estimated climb rate after takeoff was 5.6 ± 0.5 feet per second.

The video camera near the helipad captured the helicopter after takeoff for about 12 seconds, including 2 seconds in which the video captured only the helicopter's shadow. The video from this camera was used to estimate the helicopter's yaw rate after takeoff. The average yaw rate during the first 8 seconds of the helicopter's flight was about 22º per second. The average yaw rate during the last 4 seconds of the helicopter's flight increased to about 45º per second. The average yaw rate during the 12 seconds of the helicopter's flight was about 30º per second.[42]

The video camera mounted on a light pole in the medical center parking lot captured the helicopter for about 1 second before it impacted the ground.[43] The video from this camera was used to estimate the helicopter's vertical speed at impact. A total of 12 video frames were analyzed.[44] The first analyzed frame showed the helicopter when it was first fully visible within a frame. (The helicopter was partially visible in four previous frames.) At this time, the helicopter was in a 50º right bank. The last analyzed frame showed the helicopter impacting the ground. Analysis of the video showed that the helicopter impacted the ground with small pitch and roll angles at an estimated vertical speed of 58 ± 5 feet per second (40 ± 3 mph).

1.4.2 Aircraft Performance Study

The NTSB conducted a performance study that analyzed the information shown on the video from the camera near the helipad to determine the direction of the wind compared with the helicopter's orientation. The video showed that the helicopter appeared to be initially aligned (before flight) with an aircraft hangar seen directly behind the helicopter; the roofline of the hangar was along a heading of 057º. The video also captured the motion of the windsock at the site, which indicated that the wind direction was relatively constant and had been coming from the left of the

[41] Two fixed-speed lines—one line over the last 5.4 seconds of the 8-second interval, and the other line over the last 2.9 seconds of the interval—were fitted to the data to show the estimated elevation of the helicopter above the ground. The slopes of these lines, 5.1 and 6.1 feet per second, were the lower and upper estimated climb rate values, respectively.

[42] Because these yaw rates were estimated by visually inspecting the video, the accuracy of the estimates is about ± 10%.

[43] The video from this camera also captured the accident-related events that occurred during the next 10 minutes, including those described in table 1 (the first 1 minute 47 seconds of the video).

[44] The estimates were based on a mathematical model of the camera that was used to project reference points onto frames from the video and align the projected points with their images in the frames. For additional information about the method used to analyze this video, see the video study in the NTSB's docket for this accident (CEN15MA290).

helipad. The windsock appeared horizontal or below horizontal (indicating a wind of 15 knots or less) as the helicopter departed.

The performance study also considered the helicopter's tail rotor effectiveness in the wind conditions at the time of the accident. A loss of tail rotor effectiveness (LTE) occurs when airflow through the tail rotor is disrupted and, consequently, the tail rotor cannot provide enough thrust to counter the helicopter's natural tendency to yaw toward the advancing main rotor blade (main rotor torque effect). As stated in section 1.3.4, the AS350 B3e main rotor turns in a clockwise direction and thus imparts a left (counterclockwise) yaw on the helicopter (when viewed from above).

The airflow relative to a helicopter can contribute to the onset of LTE.[45] For helicopters with a clockwise main rotor, such as the AS350 B3e, LTE is a risk when the wind direction is from 30° to 240° (relative to the nose of the helicopter) because (1) a right quartering headwind (from 45º to 75º) can blow the main rotor vortex into the tail rotor, causing interference with the tail rotor and making it less effective; (2) wind from behind the helicopter (120° to 240°) can cause the helicopter to weathervane, leading to a loss of control if the pilot does not properly respond; and (3) wind from the right (30° to 150°) can cause a tail rotor vortex ring state, which results in a non-uniform, unsteady flow into the tail rotor, reducing its effectiveness.[46] The windsock in the video and the 1335 observation from the closest official weather station indicated that the wind was from the helicopter's left (about 270º compared with the helicopter's heading). Although LTE can result in a loss of control (if not detected and corrected promptly), the wind direction (from the helicopter's left at the time of takeoff) was not consistent with LTE.

Even though the wind from the left was not consistent with LTE, wind from that direction would exacerbate the AS350 B3e helicopter's left yaw tendency and require more right pedal to keep the helicopter's heading constant. The NTSB performed a simulation that modeled the pedal input required to hold the helicopter steady for different wind speeds and directions. The NTSB used the FlightLab computer-based mathematical modeling simulation tool to replicate an AS350 helicopter with a gross weight of 4,720 pounds operating at an elevation of 9,042 feet on a 73º F day—consistent with the accident helicopter's operating weight and the environment at the time of the accident.[47] The simulations were run for a hover in ground effect for wind speeds between 5 and 40 knots (in 5-knot increments) at every 20º of wind direction.[48]

Pedal inputs were reported as 0% for full left pedal, 50% for neutral/no pedal input, and 100% for full right pedal. The simulation results showed that wind directly from the helicopter's left required the greatest amount of right pedal to hold the helicopter's heading constant. For 15 knots of wind (the approximate wind speed at the time of the accident), 67.5% pedal (right

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[45] Factors that affect tail rotor aerodynamic performance, such as density altitude, can also contribute to the onset of LTE.

[46] For more information, see the FAA's *Helicopter Flying Handbook* (FAA-H-8083-21A).

[47] The FlightLab AS350 simulation model was developed by Advanced Rotorcraft Technology, Inc. For more information about this simulation tool, see the company's website (www.flightlab.com, accessed February 2, 2017).

[48] These simulations, as well as the others discussed in this section, were steady state and assumed that the helicopter did not already have a developed yaw rate to counteract. If the helicopter had already been yawing, more pedal input would have been necessary to arrest the motion.

pedal depressed about one-third of the way) was needed to maintain a steady 0º heading. For 30 knots of wind, about 78% pedal (right pedal depressed two-thirds of the way) was required.

Airbus Helicopters also performed a computer-based mathematical modeling simulation of the AS350 B3e for different wind speeds and directions for the specific conditions of the day of the accident with the helicopter hovering in ground effect. Those simulations showed that, with a 15-knot left crosswind, about 83% pedal was needed. Airbus Helicopters' simulation also showed that the helicopter would have needed 78% pedal to maintain heading with no crosswind and 95% pedal to maintain its heading with a 30-knot crosswind.[49] Although the necessary pedal inputs resulting from the FlightLab and Airbus Helicopters' simulations were different, both simulations indicated that adequate right pedal should have been available to compensate for the wind conditions at the time of the accident.

Airbus Helicopters conducted additional simulations to estimate left yaw rates that would develop when the 83% pedal input (from the results of the previously discussed simulation) was reduced by specific amounts. Five different simulations were conducted. An initial pedal input of 83% was made during the first second of each of the five simulations. After 1 second, the 83% pedal input was reduced for each simulation by one of five values—10%, 15%, 20%, 25%, or 30%—resulting in five different left yaw rates. The yaw rates 4 seconds after the reductions in pedal were about 50º per second with a 10% reduction in pedal, about 75º per second with a 15% reduction in pedal, about 95º per second with a 20% reduction in pedal, 110º per second with a 25% reduction in pedal, and 125º per second with a 30% reduction in pedal.[50]

Last, the NTSB evaluated the yaw rates of the AS350 B3e helicopter involved in the Albuquerque accident (see section 1.3.5.3) to have another yaw rate comparison point. (As previously stated, the pilot involved in the Albuquerque accident reported that he was unable to make any pedal input.) The NTSB's video study for that accident (which was based on the video from a camera mounted on the hospital rooftop) found that, about 8 seconds after takeoff, the helicopter's yaw rate was greater than 100º per second and was continuing to increase. The video study also found that a maximum yaw rate of 170º per second was reached about 15 seconds after takeoff.

1.4.2.1 Additional Meteorological Information

A witness to the Frisco accident, who was located 1/4 mile north-northwest of the accident site, took photographs of the smoke plume after the accident occurred. The smoke plume appeared to be blowing away from the accident site in a southwest-to-west direction, which was a different wind direction than that observed from the windsock at the helipad when the helicopter departed. The southwesterly direction of the smoke plume likely indicated that updrafts in the mountainous terrain were occurring near the accident site about the time of the accident, which matched a

[49] Airbus Helicopters noted that these simulation results should not be considered to be definitive performance data.

[50] Airbus Helicopters noted that this simulation might overestimate the yaw rate because the simulation model did not account for the aerodynamic effects of the vertical fin at given angles, the interaction between the vertical fin and tail rotor at a given yaw rate, inertial factors, the dampening effects of the tailboom, or wind effects during rotation.

Weather Research and Forecasting Model simulation.[51] Also, the difference in the wind direction between the smoke plume and the windsock likely indicated that low-level wind shear was present at the accident site about the time of the accident.

In addition, observations from the automated weather station at Soda Creek indicated a gusty northwest wind near the surface, and the closest terminal aerodrome forecast predicted gusty wind conditions near the accident site.[52] The stronger wind and low-level wind shear conditions were associated with a dissipating rain shower north of the accident site (just before the accident time) and a developing rain shower south-southwest of the accident site (at and just after the accident time).

1.4.2.2 Analysis

Low-level wind shear, gusty surface winds, and updrafts in the mountainous terrain were occurring during the time surrounding the accident. However, video indicated that the wind direction near the ground was constant during the takeoff, yet the helicopter quickly developed a significant yaw rate. Further, simulations of the helicopter in its takeoff configuration indicated that the helicopter should have had enough tail rotor authority to control the left yaw with the reported wind speed at the time of the accident and with direct crosswinds as high as 30 knots. Thus, the NTSB concludes that the wind conditions at the time of the accident would not have prevented the pilot from maintaining yaw control of the helicopter.

The calculated yaw rates of the accident helicopter (22º to 45º per second) were significantly less than those shown in Airbus Helicopters' simulations (50º to 125º per second) and those involved in the AS350 B3e accident in Albuquerque (greater than 100º per second after about 8 seconds). These yaw rates indicated that the pilot involved in the Frisco accident was able to input some amount of right pedal, resulting in some amount of tail rotor control. The accident scenario is discussed in section 1.5.

1.4.3 Pedal Control Loads

1.4.3.1 Pedal Loads to Maintain Heading at Takeoff

During the investigation of this accident, the NTSB requested that Airbus Helicopters calculate the pedal control loads required for an AS350 B3e helicopter to maintain a steady heading when hovering in ground effect.[53] These calculations assumed conditions similar to those

[51] The simulation of the weather conditions surrounding the accident site at the accident time showed horizontal wind speeds between 15 to 25 knots with higher gusts and updrafts with a velocity between 300 and 1,000 feet per minute near the mountainous terrain.

[52] The closest National Weather Service facility with a terminal aerodrome forecast was located at Eagle, Colorado (39 miles west of the accident site). The forecast that was in effect at the time of the accident was issued at 1235 and was valid for a 23-hour period beginning at 1300. The forecast predicted that, between 1300 and 1700, the wind would be variable at 20 knots with gusts to 30 knots and that light rain and thunderstorms would be occurring.

[53] Pedal control loads, as described in this report, are the forces that the pilot exerts to move to or maintain a pedal position.

on the day of the accident: a helicopter weight of 4,720 pounds, a temperature of 73º F, and an altitude of 9,170 feet.[54] Two wind conditions were analyzed: a 0-knot (no wind) condition and a 15-knot wind originating from the helicopter's left (the estimated wind condition at the time of the accident).

Three different tail rotor hydraulic circuit configurations affecting pedal control loads were considered. First, the yaw servo hydraulic switch was in the "ON" position, and the "ACCU TST" push button was not activated, resulting in normally boosted (hydraulically assisted) pedals. Second, the yaw servo hydraulic switch was in the "OFF" position, and the "ACCU TST" push button was not activated, resulting in partially boosted pedals. Last, the yaw servo hydraulic switch was in the "OFF" position, and the "ACCU TST" push button was activated, resulting in nonboosted pedals. Table 2 shows the calculated right pedal control load for each of these configurations. As stated in section 1.4.2, Airbus Helicopters' simulation estimated that a pedal position of 78% was required in a no-wind condition to maintain a steady heading when hovering in ground effect; with a 15-knot left wind condition, a pedal position of about 83% was required.

Table 2. Calculated right pedal control loads for different tail rotor hydraulic circuit configurations.

Tail rotor hydraulic circuit configuration	Yaw servo hydraulic switch position	Tail rotor servo control condition	"ACCU TST" push button position	Yaw load compensator accumulator condition	Approximate pedal control load with no wind (in pounds)	Approximate pedal control load with 15-knot wind from left (in pounds)
Boosted	On	Boosted	Not activated	Charged	3 to 5	3 to 5
Partially boosted	Off	Not boosted	Not activated	Charged	29	45
Nonboosted	Off	Not boosted	Activated	Depleted	142	161

Note: The position of the yaw servo hydraulic switch and "ACCU TST" push button resulted in the condition of the tail rotor servo control and the yaw load compensator accumulator, respectively.

1.4.3.2 Pedal Loads During Hydraulic Check

The NTSB, along with the FAA, Airbus Helicopters, and Air Methods, performed postaccident testing at an Airbus Helicopters facility in Grand Prairie, Texas, to determine the pedal control loads on an exemplar AS350 B3e helicopter after conducting the yaw servo hydraulic check. The check was first performed according to the steps in the preflight checklist that was current at the time of the accident (see section 1.3.5.1) and then by modifying the steps in the checklist involving the yaw servo hydraulic switch and the "ACCU TST" push button.[55] These 11 combinations resulted in 4 separate configurations for both the tail rotor servo control and the

[54] The altitude that Airbus Helicopters used in this simulation (derived from Google Earth) differed from that used in the simulations discussed in section 1.4.2 by 128 feet, which was considered inconsequential to the results of this simulation.

[55] During the tests, the helicopter was on the ground with the engine twist grip (on the collective stick) in the idle position. The wind was from 170º at 5 knots, the helicopter's magnetic heading was 180º, and the helicopter's weight was 4,720 pounds. A hand-held force gauge was used to measure the pedal control loads on both the left and right pedals, and three measurements were taken for each pedal to ensure consistency among the pedal control load measurements.

yaw load compensator accumulator. Pedal control loads were measured when initial pedal movement was observed. Table 3 shows the average pedal control loads measured for each configuration.[56]

Table 3. Measured pedal control loads for different tail rotor hydraulic circuit configurations.

Tail rotor hydraulic circuit configuration	Tail rotor servo control condition	Yaw load compensator accumulator condition	Approximate left pedal control load (in pounds)	Approximate right pedal control load (in pounds)
Boosted	Boosted	Charged	3	2
Boosted	Boosted	Depleted	3	2
Partially boosted	Not boosted	Charged	60	34
Nonboosted	Not boosted	Depleted	28	39

1.5 Accident Scenario Analysis

The surveillance videos of the accident helicopter's takeoff showed the onset of a left yaw occurring simultaneously with liftoff. According to the NTSB's video study, the left yaw had an initial average yaw rate of 22º per second. This yaw rate and the results of yaw simulations performed by Airbus Helicopters were consistent with a partial right pedal input by the pilot at takeoff. However, the left yaw rate increased as the helicopter gained altitude, which was consistent with increasing main rotor torque without a sufficient increase in tail rotor thrust to maintain a steady heading. The video study found that the average yaw rate had increased to 45º per second as the helicopter departed the helipad.

During the onset of the left yaw and while the helicopter was still close to the ground, the pilot had to decide whether to immediately reduce main rotor collective pitch and land or continue the takeoff to gain forward airspeed (and mitigate the left yaw). The evidence suggested that the pilot most likely increased the collective input with an intent to fly out of the left yaw rotation, which also increased the helicopter's altitude. However, the left yaw rotation subsequently increased, causing the helicopter to spin. The pilot then reduced main rotor collective pitch, which decreased the helicopter's altitude. A surveillance video captured the helicopter descending to the ground at a high vertical descent rate with a steep (50º) right bank, which was likely due to unsteady control inputs caused by the inertial effects of spinning.[57] The helicopter subsequently impacted the RV and the ground. The circumstances leading to the accident are discussed in the sections that follow.

1.5.1 Loss of Tail Rotor Control

As previously stated, the helicopter's increasing left yaw rate was consistent with increasing main rotor torque without a sufficient increase in tail rotor thrust to maintain a steady heading. The three likely causes for insufficient tail rotor thrust are a loss of (1) tail rotor drive,

[56] For the partially boosted and nonboosted configurations, pedal control loads increase as the pedal is pushed farther forward.

[57] Controllability becomes a major concern when a helicopter is spinning due to the inertial forces that the pilot feels. Specifically, when a helicopter is spinning nose left, the pilot tends to get pushed to the right of the seat, which makes it difficult to maintain steady and coordinated inputs.

(2) tail rotor effectiveness, and (3) tail rotor control. On the basis of the findings from the investigation of this accident, the NTSB excluded a loss of tail rotor drive and LTE as possible causes for the insufficient tail rotor thrust (see sections 1.3.3.3 and 1.4.2, respectively). Thus, a loss of tail rotor control caused the left yaw at the time of takeoff.

The loss of tail rotor control could have resulted from a physical restriction within the tail rotor flight control system, but the lack of evidence (that is, no witness marks) indicating such a restriction within the forward tail rotor flight controls eliminated that possibility.[58] The loss of tail rotor control could also have resulted from a disconnect within the tail rotor flight control system, but that possibility was discounted because of evidence indicating that the pilot made a partial right pedal input at takeoff. In addition, no recent maintenance had been performed on the tail rotor flight controls, and no evidence indicated any disconnect within the tail rotor flight controls.

Another reason for a loss of tail rotor control is a partial or full loss of hydraulic boost to the pedals. In an AS350 B3e helicopter, a partial or full loss of hydraulic boost to the pedals could be caused by a loss of hydraulic pressure to the lower hydraulic system or a malfunction of the tail rotor hydraulic isolation valve. For either of these conditions, if the tail rotor hydraulic circuit were correctly configured—the yaw servo hydraulic switch reset to the “ON” position and the yaw load compensator accumulator charged—after the yaw servo hydraulic check, the yaw load compensator would provide partial hydraulic assistance to the pedals. Airbus Helicopters calculated that the necessary pedal force to maintain a steady heading with partial hydraulic assistance would be about 30 to 45 pounds.

A partial or full loss of hydraulic boost to the pedals could also be caused by an incorrectly configured tail rotor hydraulic circuit (as a result of the yaw servo hydraulic check not being performed correctly).[59] If the yaw servo hydraulic switch were not reset to the “ON” position and the yaw load compensator accumulator were depleted, the pilot could experience a lack of hydraulic boost to the pedals. Airbus Helicopters calculated that the necessary pedal force to maintain a steady heading would be about 161 pounds.

If the yaw servo hydraulic switch were not reset to the “ON” position but the yaw load compensator accumulator were charged and thus providing hydraulic boost to the pedals, the pilot would likely have been able to input enough pedal force (30 to 45 pounds) to control yaw. However, if the yaw load compensator accumulator were depleted, the pilot might not have input enough pedal force (161 pounds) to control yaw, especially if he perceived that the increased pedal loads might have been due to a tail rotor control failure. Thus, because the pilot was unable to maintain the helicopter’s heading during and after takeoff and was unable to control the left yaw rotation, the helicopter likely experienced a lack of hydraulic boost to the pedals as a result of the yaw servo hydraulic switch being in the “OFF” position and the yaw load compensator accumulator being depleted. (The most likely reason for the switch being in that position is discussed in the next section.) The NTSB concludes that a lack of hydraulic boost to the pedals,

[58] Similarly, during the investigations of the Albuquerque accident and the Temple, Texas, incident, the NTSB found no evidence of a physical restriction to explain the locked-pedal feeling that both helicopter pilots reported.

[59] A failure of the tail rotor hydraulic circuit could also result in a loss of hydraulic boost. However, in this situation, the yaw load compensator would provide backup hydraulic boost to the pedal controls (as long as the pilot, during the yaw servo hydraulic check, accurately assessed the yaw load compensator to be functional).

resulting in significantly increased pedal loads, was the most likely cause of the loss of tail rotor control, which led to the left yaw that occurred simultaneously with takeoff.

1.5.2 Performance of Yaw Servo Hydraulic Check

As part of the yaw servo hydraulic check, the pilot was to test the functionality of the yaw load compensator by isolating hydraulic pressure to the tail rotor circuit and checking the pedal loads. The steps of the yaw servo hydraulic check, as outlined in an Air Methods' expanded checklist (see section 1.3.5.1), involved (1) moving the yaw servo hydraulic switch to the "OFF" position (which cuts off hydraulic pressure to the tail rotor hydraulic circuit) and then ensuring that pedal forces remained low (due to the yaw load compensator); (2) depressing the "ACCU TST" button, thereby releasing (depleting) the hydraulic pressure in the yaw load compensator accumulator by opening its solenoid valve, and then ensuring that loads were felt on the pedals; (3) resetting the "ACCU TST" button, thereby closing the solenoid valve (but the tail rotor hydraulic circuit remains depressurized); and (4) restoring hydraulic pressure to the tail rotor servo control and the yaw load compensator accumulator by returning the yaw servo hydraulic switch to the "ON" position. At the time of the accident, the yaw servo hydraulic check was to be performed before each flight to ensure functionality of the yaw load compensator.

Onboard video data were not available to help the NTSB determine whether the pilot performed the yaw servo hydraulic check correctly before takeoff, and the flight nurse in the right aft seat did not recall anything specific about the pilot's checklist use that day.[60] In addition, Air Methods did not have a formal process for distributing Airbus Helicopters safety information notices and SBs to pilots, and one notice, issued more than 10 months before the accident, explained that the failure to return the yaw servo hydraulic switch to the "ON" position would result in a complete lack of hydraulic boost to the pedal controls.

However, the pilot was familiar with Airbus Helicopters and Air Methods AS350 B3e preflight and pretakeoff procedures, and he had reportedly always used the checklist when performing the steps of the yaw servo hydraulic check. Also, colleagues of the pilot indicated that he was aware of the risk of taking off without hydraulic assistance to the pedals, and, on the day of the accident, there were no known pressures to depart that would have precluded the pilot from doing the required checks, including the yaw servo hydraulic check.

Given that a lack of hydraulic boost to the pedals was the most likely cause of the loss of tail rotor control, the yaw servo hydraulic switch was most likely not in its proper position at the time of takeoff.[61] As a result, the NTSB concludes that the pilot most likely did not return the yaw servo hydraulic switch to its correct ("ON") position before takeoff, resulting in a lack of hydraulic pressure to the tail rotor servo control and the yaw load compensator accumulator.

The pilot would not have had any visual or aural indications of the total loss of hydraulic boost to the pedals, and a check of the caution and warning panel during the left yaw rotation

[60] The lack of onboard video data is discussed in section 1.8.

[61] The NTSB considered the possibility that the pilot returned the yaw servo hydraulic switch to the "ON" position but did not reset the "ACCU TST" push button and found that, with the tail rotor hydraulic circuit charged and the yaw load compensator depleted, the pedal forces would be low (as shown in table 3).

would not have revealed any abnormal indications. In February 2015, Airbus Helicopters issued SB No. AS350 67.00.64 for AS350-series helicopters with a dual hydraulic system to incorporate a "HYD2" light on the caution and warning panel that would flash if the yaw servo hydraulic switch was in the "OFF" position. The pilot could use this information to infer that the tail rotor hydraulic circuit was isolated from the hydraulic pressure provided by the lower hydraulic system, which would result in increased pedal loads. (The main rotor control loads would not change because the main rotor flight controls would continue to be boosted by the upper hydraulic system.)

However, the FAA did not mandate this modification because the light would only indicate a switch position and would not alert a pilot to a loss of pressure to the tail rotor hydraulic circuit regardless of the position of the yaw servo hydraulic switch.[62] As stated in section 1.3.5.4, in November 2016, EASA issued an AD that required operators of dual-hydraulic AS350 B3 helicopters to modify their helicopters in accordance with Airbus Helicopters' February 2015 SB. As of March 17, 2017, the FAA had not mandated any modification to alert pilots of the position of the yaw servo hydraulic switch or a lack of hydraulic pressure in the tail rotor hydraulic circuit.

A light that would alert pilots when the yaw servo hydraulic switch was in the "OFF" position or when the pressure in the tail rotor hydraulic circuit was insufficient could be beneficial given that FAA AD 2015-22-53 moved the preflight hydraulic check to a postflight procedure. In our comments about the AD, the NTSB stated that "the actions required by the AD are a positive step toward reducing the risk of taking off without hydraulic pressure in the tail rotor hydraulic system" but that "a complementary aural or visual indication to alert pilots about the actual condition of the tail rotor hydraulic system would provide more robust protection against a known hazardous condition."

As of June 13, 2016, Airbus Helicopters reported providing 218 "HYD2" light modification kits to US operators, which covered almost the entire population of dual-hydraulic AS350-series helicopters in the US fleet that were in operation before the incorporation of this modification in the production line (September 2014). However, Airbus Helicopters did not require operators to provide proof of compliance with the modification, so it is unknown how many of the affected dual-hydraulic AS350-series helicopters in the US fleet have the "HYD2" light on the caution and warning panel.

As previously stated, the "HYD2" light had not been installed on the accident helicopter because Air Methods did not begin efforts to incorporate this modification on its AS350-series helicopters (with a dual hydraulic system) until 5 days after the accident. Air Methods indicated that all nonmandatory SBs had to undergo a company risk assessment before being implemented, and the risk assessment for SB No. AS350 67.00.64, which was issued about 4 months before the accident, had not yet been performed. The NTSB concludes that, although not required to do so, Air Methods did not aggressively take action to comply with Airbus Helicopters' SB No. AS350-67.00.64, which called for installing a flashing light on the cockpit caution and warning panel to alert pilots that the yaw servo hydraulic switch was in the incorrect position; if

[62] On January 14, 2016, the NTSB provided comments to the Department of Transportation regarding AD 2015-22-53 (which moved the preflight hydraulic check to a postflight check). As part of its comments about the AD, the NTSB stated the following: "the AD does not address the lack of any aural or visual warning panel indications for when the yaw servo hydraulic switch is placed in the 'OFF' (aft) position or when there is reduced or no hydraulic pressure to the tail rotor hydraulic system."

this nonmandatory SB had been complied with, the pilot might have noticed that the switch was not in the correct ("ON") position before takeoff. The NTSB also concludes that a salient alert for insufficient hydraulic pressure in the tail rotor hydraulic circuit could have cued the pilot to the incorrect configuration of the tail rotor hydraulic circuit, the lack of hydraulic boost to the pedal controls, and the resulting increased pedal loads.

In addition, as stated in section 1.3.5.3, a finding from the NTSB's investigation of the Albuquerque AS350 B3e accident was "the lack of a caution indicator to alert the pilot of the lower hydraulic system configuration." Although a visual alert would have helped the pilots involved in both the Frisco and Albuquerque accidents, the NTSB notes that current human factors design guidance for alerting pilots recommends that, whenever possible, an alert should be provided to pilots through multiple sensory modalities (for example, visual and aural or visual and tactile) to help ensure the timely capture and direction of a pilot's attention to the condition triggering the alert. Therefore, the NTSB recommends that the FAA require that existing Airbus Helicopters dual-hydraulic AS350-series helicopters be equipped with a visual and an aural alert for the loss of hydraulic boost to the pedal controls, which would result in increased pedal loads.

1.5.2.1 Tail Rotor Hydraulic Circuit Design

The incorporation of the visual and aural alert detailed in Safety Recommendation A-17-8 is only a partial solution to ensuring pedal control hydraulic assistance. AS350-series helicopters with a dual hydraulic system provide redundancy in hydraulic assistance to the main rotor flight controls via three dual-cylinder main rotor servo controls, but the single-cylinder tail rotor servo control does not provide such redundancy to the pedal controls. Instead, the yaw load compensator provides continuous hydraulic power assistance to keep pedal loads at a manageable level in the event of a depressurization of the lower hydraulic system (in which case the tail rotor servo control would no longer be hydraulically boosted).

As previously stated, at the time of the accident, pilots of dual-hydraulic AS350-series helicopters needed to assess the functionality of the yaw load compensator during the preflight yaw servo hydraulic check to ensure that the yaw load compensator could provide backup pedal control hydraulic assistance during flight. During the check, the pilots would intentionally deplete the yaw load compensator accumulator, rendering it unable to provide backup hydraulic assistance to the pedal controls until the yaw servo hydraulic switch was moved from the "OFF" position to the "ON" position, which would simultaneously restore hydraulic pressure to the tail rotor servo control and recharge the yaw load compensator accumulator.

Further, during the preflight yaw servo hydraulic check, pilots of dual-hydraulic AS350-series helicopters also needed to assess, via pedal control tactile feedback, whether the yaw load compensator was functional. As indicated in table 3, testing to determine pedal control loads for the partially boosted configuration (with the yaw load compensator accumulator charged) and the nonboosted configuration (with the yaw load compensator accumulator depleted) during the yaw servo hydraulic check showed only a 5-pound difference between the two configurations in the right pedal (34 and 39 pounds, respectively). The left pedal force decreased from 60 pounds for the partially boosted configuration to 28 pounds for the nonboosted configuration.[63]

Because pilots of dual-hydraulic AS350-series helicopters might not be able to reliably discriminate among these differences in pedal loads, there is a potential for these pilots to incorrectly assess the functionality of the yaw load compensator. In addition, for dual-hydraulic AS350-series helicopters that lack an alert on the caution and warning panel to indicate when the yaw servo hydraulic switch is in the "OFF" position, there is a risk that pilots could inadvertently leave the switch in that position.

Replacing the preflight yaw servo hydraulic check with the postflight yaw load compensator check (see section 1.3.5.4) reduced the risks associated with misconfiguring the tail rotor hydraulic circuit before takeoff. However, this action did not completely eliminate the risk of taking off without backup hydraulic boost to the pedals because the postflight check assumes that the yaw load compensator would remain functional until the start of the next flight, which might not occur.[64] Also, this action did not address the possibility that the postflight check might be performed incorrectly or that the functionality of the yaw load compensator might not have been verified. As a result, the NTSB concludes that the design of Airbus Helicopters dual-hydraulic AS350-series helicopters did not account for the possibility of pilot error in configuring the tail rotor hydraulic circuit or assessing the functionality of the yaw load compensator, and efforts to address these safety issues have thus far been insufficient.

A solution to mitigate the possibility of pilot error while also ensuring that redundancy in pedal control hydraulic assistance is consistently available could be to use the design philosophy of the main rotor flight control system (which includes dual-cylinder main rotor servo controls) and incorporate a dual-cylinder tail rotor servo control in the tail rotor hydraulic circuit. A dual-cylinder tail rotor servo control would provide redundancy for pedal control hydraulic assistance because of the availability of both the upper and lower hydraulic systems. Specifically, with a dual-cylinder tail rotor servo control, each hydraulic system would power an individual cylinder that would provide enough boost for normal operation if the other cylinder became inoperable. A dual-cylinder tail rotor servo control would also eliminate the need for a yaw load compensator and any associated check, which would mitigate the possibility of pilot error in assessing the functionality of the yaw load compensator and configuring the tail rotor hydraulic circuit.

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[63] With a partially boosted configuration, the left pedal has a higher pedal load than the right pedal. As previously stated, the yaw load compensator is biased toward the right pedal because a right pedal input is needed to counteract the main rotor torque effect. When the yaw load compensator is depleted and the pedals are in a nonboosted configuration, the left pedal load reduces because the yaw load compensator bias has been removed.

[64] For example, it is possible that the yaw load compensator might not remain functional between the time of the postflight check and the helicopter's next flight if the helicopter was grounded for extensive maintenance (unless a pilot decided to check the yaw load compensator during the preflight run-up). In addition, because the yaw load compensator functional check is now part of postflight procedures, it is possible that a pilot could experience extremely high pedal control loads if presented with a dual failure of both the yaw load compensator and a simultaneous loss of pressure to the lower hydraulic system, which could cause a loss of yaw control during flight. The FAA and Airbus Helicopters assessed that the probability of this dual failure mode was low compared with the risk of taking off with an improper hydraulic system configuration.

The NTSB recognizes that solutions other than a dual-cylinder tail rotor servo control might exist. Therefore, the NTSB recommends that Airbus Helicopters, for newly manufactured dual-hydraulic AS350-series helicopters, assess and implement changes to the dual hydraulic system that would both ensure pedal control hydraulic assistance and mitigate the possibility of pilot error during any check of the hydraulic system. The NTSB also recommends that Airbus Helicopters, for existing dual-hydraulic AS350-series helicopters, assess and implement changes to the dual hydraulic system that would both ensure pedal control hydraulic assistance and mitigate the possibility of pilot error during any check of the hydraulic system. In addition, the NTSB recommends that, after the actions requested in Safety Recommendation A-17-10 are completed, the FAA and EASA require operators of Airbus Helicopters dual-hydraulic AS350-series helicopters to incorporate changes to the dual hydraulic system to both ensure pedal control hydraulic assistance and mitigate the possibility of pilot error during any check of the hydraulic system.

1.5.3 Decision to Continue Takeoff

The helicopter was oriented in a northeast direction at takeoff, and the pilot's intended departure route was to the north, which was the normal departure route from the medical center.[65] Thus, the pilot would likely have intended for the helicopter to lift off and turn left during the departure over a valley. During a postaccident interview, the flight nurse in the right aft seat stated that the counterclockwise turn that occurred immediately at takeoff was not unusual, but he also stated that the helicopter "sort of paused momentarily with that left turn before [the helicopter] continued climbing and turning," which was "unusual for [the accident pilot]."

The flight nurse further described the takeoff as "rough" with "some unusual pitch"; if the pilot had noted the same conditions, he might have attributed them to the wind in the area at the time. Video evidence showed that the pilot had likely made some pedal input at liftoff. Although the pedal force required would have been greater than the normal pedal force at liftoff (about 3 to 5 pounds), it is possible that the pilot did not notice that he was applying the increased pedal force or thought that it was needed to compensate for the wind. Also, because the pilot intended to turn the helicopter to the left toward the north, the helicopter's initial counterclockwise rotation might not have seemed unusual to the pilot.

As the helicopter climbed and rotated toward the desired heading, the pilot would have input additional right pedal to stop the rotation and depart over the valley. At this point, a significantly increased pedal force (about 161 pounds), which the pilot was most likely not expecting, would have been required to move the right pedal to a position that would have arrested the left yaw rotation. (Video evidence also showed that the helicopter's altitude at that time was about 10 feet or less.) Despite the pedal control anomaly, the pilot continued the takeoff. The NTSB examined why the pilot might have continued the takeoff rather than land once he became aware of the anomaly.

[65] North was the normal departure route from the medical center because of nearby obstacles, which included an aircraft hangar and a fuel tank (next to the hangar) to the southwest, rapidly rising terrain to the south, a hospital to the east, a light pole to the northeast, and trees in the area.

Given the helicopter's left yaw rotation, its altitude, and the nearby aircraft hangar and other obstacles, the pilot might have thought that it would be unsafe to attempt an emergency landing on the helipad. Also, the pilot was aware of the AS350 B3e event in Albuquerque (and possibly the event in Temple, Texas) and might have been concerned about the outcome of the Albuquerque accident.[66] Specifically, that pilot's decision to reduce main rotor collective pitch (to decrease altitude) after a continuing left yaw during takeoff resulted in major damage to the helicopter, as seen in the surveillance video for that accident.[67] Thus, the pilot involved in the Frisco accident might have thought that increasing collective pitch to climb above the hangar would be the best option because the helicopter could then gain forward airspeed and fly out of the left yaw rotation.

The flight nurse in the right aft seat stated that he thought that the pilot had attempted to have the helicopter gain forward airspeed. He also stated that the helicopter began spinning "violently" counterclockwise after a "very brief forward flight." The pilot tried but was not able to maintain control of the helicopter, which subsequently descended and struck the ground. The NTSB concludes that, despite the significantly increased pedal loads, the pilot continued the takeoff to climb the helicopter above nearby obstacles and gain forward airspeed to counter the left yaw rotation, but his efforts were unsuccessful.

The NTSB notes that the dent found on the directional control lateral push-pull tube was consistent with the right pedal in its fully forward position at ground impact. This evidence, along with the forward position of the yaw servo hydraulic switch, indicated the possibility that, after the pilot recognized the severity of the pedal control anomaly, he also recognized that the yaw servo hydraulic switch was in the "OFF" position and then moved the switch to the "ON" position. However, this action would likely have occurred with insufficient time remaining to allow recovery of the helicopter.[68]

1.5.4 Failure to Perform a Hover Check

Air Methods and Airbus Helicopters takeoff procedures included a step in which the helicopter lifted off to a hover so that pilots could check that systems were functioning properly and that no warnings were occurring. Performing such a check would also allow pilots to verify a helicopter's controllability. Although Air Methods pilots stated, during postaccident interviews, that the hover check was always completed at the start of takeoff, video evidence showed that a

[66] During a November 2015 postaccident interview with the NTSB, a Flight For Life assistant nurse manager who had flown with the pilot involved in the Frisco accident stated that the pilot had reviewed the video of the Albuquerque accident. The assistant nurse manager also stated that the Albuquerque accident "had a lot of people upset" because the "helicopter was spinning and completely out of control."

[67] In the Temple, Texas, incident, the pilot's decision to reduce main rotor collective pitch after a continuing left yaw during takeoff resulted in a hovering autorotation.

[68] A video of the US Customs and Border Protection AS350 B3 event (see section 1.3.5.3) showed that the helicopter was spinning but was successfully recovered after about seven or eight rotations. The pilot had reportedly moved the yaw servo hydraulic switch to its correct position during that time, which allowed him to input right pedal to counter the spinning motion.

hover check was not performed at the start of the accident takeoff.[69] In addition, the NTSB considered whether the pilot's right pedal input could have been the start of the hover check but determined that possibility was unlikely for two reasons. First, the right pedal input was an expected part of the departure from the helipad (to stop the left turn that normally occurred, which was more rapid than usual on the day of the accident). Second, if the right pedal input was made to start the hover check, the pilot would likely have noticed an anomaly with the helicopter's pedal controls at that point and immediately reduced main rotor collective pitch to land the helicopter.[70]

If the helicopter had lifted off to a hover, the pilot would likely have recognized that there was little to no pedal movement to stop the helicopter's counterclockwise rotation. The NTSB concludes that, if the pilot had performed a hover check, he would have identified the pedal control anomaly at an altitude that could have afforded a safe landing on the helipad.

After the accident, Airbus Helicopters issued Safety Information Notice No. 2992-S-00 (dated January 21, 2016) to remind pilots of best practices that would help ensure a safe takeoff. Those best practices included the following: "ensure that normal loads are felt on the flight controls (cyclic, collective, yaw pedals)"; "check that switch positions and cockpit configuration (caution and warning lights out) are correct for the phase of flight"; and "perform a hover flight at around 5 ft. and confirm the normal behavior of the aircraft." The notice indicated that common errors could occur if pilots became complacent in their operating routine and that, if the initial hover check was not performed, the opportunity to detect and respond to unexpected aircraft behavior, with the appropriate power and control, could be limited.

Also, on November 15, 2016, the FAA issued Safety Alert for Operators (SAFO) 16016, "Helicopter Stabilized Hover Checks Before Departure." In the SAFO, the FAA noted that several recent helicopter accidents had occurred as a result of pilots not bringing the helicopter to a stabilized hover before initiating takeoff. The SAFO recommended that pilots "always perform a hover check prior to takeoff" (unless prohibited by environmental conditions). The SAFO also recommended that pilots abort the takeoff "if at any time during initial collective pull the helicopter does not appear to be stabilized." The NTSB concurs that pilots should perform stabilized hover checks before takeoff.

1.6 Survival Factors

1.6.1 General

As indicated in table 1, surveillance video showed that the helicopter came to rest on its right side about 1 second after impact with the ground. The fuel tank ruptured, and a large quantity of fuel flowed from beneath the helicopter wreckage. The released fuel ignited, and a fire was first visible on the video about 3 seconds after ground impact. The postcrash fire consumed most of the helicopter. The flight nurse in the left aft seat (see section 1.6.2 for information about the seating

[69] Video evidence of the Albuquerque accident indicated that the pilot involved in that accident also did not perform a hover check during the initial takeoff. The NTSB could not determine whether the pilot involved in the Temple, Texas, incident performed a hover check.

[70] The NTSB attempted to determine the frequency that Air Methods helicopter pilots performed hover checks at 91CO, as discussed in section 1.8.

configuration) was seen on the video emerging from underneath the left-side door panel, which had separated from the helicopter; he was also seen running away from the helicopter while engulfed in flames. The flight nurse in the right aft seat was seen climbing out the left-side door region and dropping to the ground. The video also showed that, after evacuating the helicopter from the cockpit with the assistance of a bystander, the pilot rolled away from the helicopter while the bystander used a fire extinguisher to put out a fire that had ignited on the pilot.[71]

The NTSB's video study for this accident found that the vertical impact velocity at the helicopter's nose was about 58 ± 5 feet per second.[72] (The frame rate of the surveillance video was not sufficient to determine the helicopter's vertical impact deceleration.)[73] In the early 1990s, the FAA conducted a civil rotorcraft research program to evaluate crash-resistant design technology and found that significant reductions in occupant injuries could result if civil rotorcraft were designed for vertical impact velocities of 26 feet per second (Coltman 1994).[74] Military standards indicated that military rotorcraft were designed to withstand vertical impact velocities of 42 feet per second (DoD 1988).

1.6.1.1 Analysis

The calculated vertical impact velocity of the accident helicopter (58 ± 5 feet per second) was well above the thresholds established by the FAA's civil rotorcraft research program (26 feet per second) and the military rotorcraft design standard (42 feet per second). However, despite the high vertical impact velocity, the three helicopter occupants initially survived the accident.

The pilot subsequently died from his accident-related injuries. He received extensive blunt force trauma injuries, significant thermal lung injuries, and second- and third-degree burns. Even with these extensive injuries, the pilot was able to speak after the accident. However, the pilot's significant thermal lung injuries greatly decreased his chances of survival.[75]

The flight nurse in the right aft seat received multiple blunt force injuries that were not an immediate threat to life, and he did not sustain thermal injuries. The flight nurse in the left aft seat received thermal injuries with burns over 90% of his body, resulting in a high threat to life. He also received multiple blunt force injuries that were not an immediate threat to life. The pilot's

[71] Air Methods provided long-sleeve Nomex flight suits for personnel operating on its helicopters. These flight suits were fire-resistant and designed to withstand temperatures up to 400º C (752º F) and quickly self-extinguish when removed from flame sources.

[72] Airbus Helicopters evaluated the surveillance video and calculated that the vertical impact speed at the helicopter's center of gravity was 42 feet per second. Airbus Helicopters also calculated that, given the pitch rate immediately before impact, the vertical impact speed at the forward seat location was 59 feet per second.

[73] G is a unit of measurement of deceleration and acceleration. One G is equivalent to the acceleration caused by the earth's gravity (about 32.2 ft/sec^2).

[74] The program found that occupant survivability in the civil helicopter fleet that was current at the time was most affected by vertical impact velocity (compared with longitudinal and lateral impact velocities), with a velocity of 30 feet per second being the transition from potentially survivable to unsurvivable.

[75] The most significant injuries to the pilot were the thermal injuries to his lungs. Although the pilot initially survived his blunt force trauma injuries, the thermal injuries to his lungs likely impaired oxygenation of his blood during resuscitation efforts and contributed significantly to his death.

blunt force trauma injuries were more severe than those that the flight nurses received likely because of the helicopter's nose-down impact with the ground, resulting in more force to the pilot's seat than the medical crew seats. The NTSB concludes that the impact forces of this accident were survivable for the helicopter occupants. The thermal injuries sustained by the pilot and the flight nurse in the left aft seat are further discussed in section 1.6.3.2.

1.6.2 Pilot and Medical Crew Seats

The helicopter was equipped with four occupant seats and one patient litter, as shown in figure 5. The pilot's seat was located at the front of the cabin on the right side. The litter was adjacent to the pilot's seat on the left side of the helicopter next to an emergency exit door. The three forward-facing medical crewmember seats were mounted to the aft bulkhead.

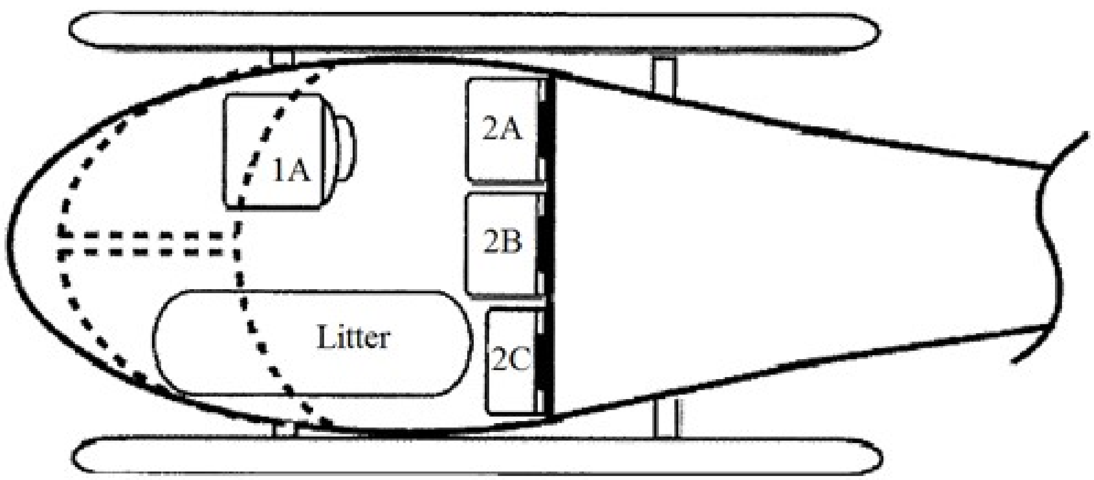

Figure 5. Occupant seating positions on N390LG.

Note: The pilot was in seat 1A, the flight nurse who sustained blunt force injuries only was in seat 2A, and the flight nurse who sustained blunt force and thermal injuries was in seat 2C.

The pilot's seat was manufactured by Zodiac Seats France. The seat had an integral four-point inertia reel restraint with rotary buckle and a combined lap/shoulder belt latch. The pilot's seat was designed to comply with Technical Standard Order (TSO) C127a, "Rotorcraft, Transport Airplane, and Normal and Utility Airplane Seating Systems." The three medical crewmember seats were installed according to a supplemental type certificate (STC) that the FAA issued to Air Methods on December 5, 2003.[76] Each seat had a four-point restraint system.

The three medical crewmember seats were certified to the original requirements of 14 *CFR* 27.561(b)(3), which became effective on February 1, 1965.[77] The pilot's seat was certified

[76] An STC authorizes the alteration of an aircraft component or system that is operated under an approved type certificate.

[77] Title 14 *CFR* 27.561(b)(3) provided the ultimate inertial load factors for occupant safety during emergency landing conditions. The regulation specified the following ultimate inertial load factors: 1.5 G upward, 4.0 G forward, 2.0 G sideward, and 4.0 G downward or "any lower force that will not be exceeded when the rotorcraft absorbs the

to meet the requirements of the regulation at the levels specified by amendment 27-25, which became effective on December 13, 1989.[78] In addition, the pilot's seat was tested to meet the emergency landing dynamic testing requirements of 14 *CFR* 27.562(b), which also became effective on December 13, 1989.[79] The medical crewmember seats were not required to undergo the dynamic testing specified in section 27.562(b) because the regulation was not part of the certification basis for those seats, even though the STC date was after the regulation date.

The pilot's seat was found in the wreckage severely damaged by the postcrash fire, but the seat was still attached to the helicopter's frame and seat track. Extensive fire damage to the fuselage prevented the identification of the right and center medical crewmember seats. The left medical crewmember seat was found away from the fuselage in front of the RV with the seat frame twisted and fire damaged, and the seat pan cushion was located nearby with no fire damage. The security and condition of airframe attachment points for the medical crewmember seats could not be examined due to fire damage.

1.6.2.1 Analysis

The pilot's seat was designed according to the requirements of a 1989 amendment to the emergency landing crashworthiness standards, which included a downward load factor of 20 G for occupant restraint within a structure. The pilot's seat was severely damaged by the postcrash fire but was retained within the airframe. Thermal damage to the floor beneath the pilot's seat and the surrounding structure prevented postcrash measurements of vertical seat stroking and the seat's vertical position relative to the floor structure.

The three medical crewmember seats were certified to the 1965 crashworthiness standards, which required a 4-G downward load factor. The flight nurse in the right aft seat stated that, after the impact with the ground, he did not see the flight nurse to his left but instead saw a hole on that side of the helicopter. The hole was likely caused by the detachment of the left-side door panel during ground impact. After the accident, the flight nurse in the left aft seat emerged from under the left-side door panel on the ground as the fire progressed. Given the observations of the flight nurse in the right aft seat, the final resting position of the left medical crewmember seat, and its limited fire damage, the NTSB concludes that the flight nurse in the left aft seat had likely been

landing loads resulting from impact with an ultimate descent velocity of five feet per second at design maximum weight."

[78] Amendment 27-25 to 14 *CFR* 27.561(b)(3) increased the ultimate inertial load factors to 4 G upward, 16 G forward, 8 G sideward, and 20 G downward after the intended displacement of the seat device (54 *Federal Register* 47318) (NARA 1989). A subsequent amendment, 27-32, which became effective on June 11, 1996, added a rearward ultimate inertial load requirement of 1.5 G to the regulation.

[79] Title 14 *CFR* 27.562 specified the following tests using a 170-pound anthropomorphic test dummy: a downward test at a minimum of 30 G peak floor deceleration (pitched at 30º) with a minimum impact velocity of 30 feet per second and a forward test at a minimum of 18.4 G peak floor deceleration (yawed at 10º) with a minimum impact velocity of 42 feet per second. According to FAA Advisory Circular (AC) 27-1B, "Certification of Normal Category Rotorcraft," the dynamic testing requirements of section 27.562 evaluate the seating system's structural performance and its ability to provide occupant protection in an emergency landing situation. This testing is different from the static test methods specified in section 27.561, which focus on only the structural strength of the seating system when ultimate loads are applied for at least 3 seconds.

restrained in his seat and was likely ejected from the helicopter with his seat during the accident sequence.

Even though the medical crewmember seats were installed on the helicopter via a 2003 STC, they did not meet, and were not required to meet, the requirements of the 1989 amendment for occupant safety during emergency landing conditions. The vertical impact velocity experienced during this crash (58 ± 5 feet per second) was greater than the descent velocity that the medical crewmember seats were required to withstand (5 feet per second).[80] However, there was insufficient evidence to determine whether the blunt force trauma injuries to the flight nurse in the right aft seat would have been reduced if the medical crewmember seats had met the improved crashworthiness standards. Further, due to the postcrash fire, there was insufficient information to determine whether the detachment of the left aft seat from the helicopter was due to maintenance, installation, or design factors.

1.6.3 Crash-Resistant Fuel Systems

The accident helicopter did not have, and was not required to be equipped with, a crash-resistant fuel system (CRFS). The first of the AS350-series helicopters approved in the United States, the AS350C, received initial FAA type certificate design approval on December 21, 1977. On October 3, 1994, the FAA revised Part 27 airworthiness standards, via amendment 27-30, to add “comprehensive crash resistant fuel system design and test criteria” for newly certificated rotorcraft (59 *Federal Register* 50380) (NARA 1994).[81] The revisions included a new regulation, 14 *CFR* 27.952, “Fuel System Crash Resistance.”

The improved crash resistance standards incorporated fuel system design features “to minimize the hazard of fuel fires to occupants following an otherwise survivable impact.” These design features were intended to reduce the risk of a postcrash fire and, for more severe crashes, minimize fuel spillage near ignition sources to improve the evacuation time needed for crew and passengers to escape a postcrash fire. The improved standards were not applicable to newly manufactured helicopters whose certification basis and approval predated the effective date of the revised airworthiness standards (November 2, 1994).

Airbus Helicopters stated that, in March 2015, a CRFS became standard equipment for newly manufactured AS350 B3e helicopters and that the first AS350 B3e helicopter equipped with a CRFS was delivered in late 2015. Airbus Helicopters and Air Methods stated that, before the Frisco accident, no options were available for retrofitting an AS350 B3e helicopter with a CRFS. On March 3, 2016, Airbus Helicopters issued an SB to provide operators of existing AS350 B3e helicopters with the option to retrofit their helicopters with a CRFS.[82] According to Airbus Helicopters, the AS350 B3e CRFS (used in newly manufactured helicopters and retrofit kits) was

[80] As previously stated, 14 *CFR* 27.561(b)(3) specified a 4-G downward load factor or “any lower force that will not be exceeded when the rotorcraft absorbs the landing loads resulting from impact with an ultimate descent velocity of five feet per second at design maximum weight.”

[81] The FAA similarly revised 14 *CFR* Part 29 airworthiness standards for transport-category rotorcraft.

[82] As of March 17, 2017, 168 AS350 B3e helicopters were operating in the United States.

based on the design of the EC130 T2 CRFS, which was certified according to the requirements of section 27.952.

1.6.3.1 Previous Related Safety Recommendations

Safety Recommendation A-15-12

Because the fuel systems on newly manufactured rotorcraft with type certificates approved before November 1994 were not subject to fuel system crash resistance regulations and, as a result, might pose a hazard to occupants if the system were breached during a crash, the NTSB issued Safety Recommendation A-15-12 on July 23, 2015.[83] The recommendation asked the FAA to do the following:

> Require, for all newly manufactured rotorcraft regardless of the design's original certification date, that the fuel systems meet the crashworthiness requirements of 14 *Code of Federal Regulations* 27.952 or 29.952, 'Fuel System Crash Resistance.'

On September 28, 2015, the FAA stated that it started the rulemaking process by sending a tasking statement to the Aviation Rulemaking Advisory Committee (ARAC).[84] On November 2, 2015, the NTSB classified this recommendation "Open—Acceptable Response" pending the issuance of the final rule.

Safety Recommendations A-16-8 through -11

On April 19, 2016, the NTSB issued Safety Recommendations A-16-8 through -10 to the FAA and Safety Recommendation A-16-11 to EASA to address the need for owners and operators of existing AS350 B3e helicopters (and similarly designed variants) to incorporate a CRFS into their rotorcraft.[85] Safety Recommendations A-16-8 through -10 asked the FAA to take the following actions:

> Once Airbus Helicopters completes development of a retrofit kit to incorporate a crash-resistant fuel system into AS350 B3e and similarly designed variants, prioritize its approval to accelerate its availability to operators. (A-16-8)
>
> Issue a special airworthiness information bulletin (SAIB) informing all owners and operators of AS350 B3e and similarly designed variants of the availability of a crash-resistant fuel system retrofit kit and urging that it be installed as soon as

[83] The accident that prompted this recommendation was case number CEN15FA003.

[84] The FAA tasked the ARAC's Rotorcraft Occupant Protection Working Group with reviewing the airworthiness standards for older helicopter type-certificated designs that are still in production. The FAA also tasked the working group with making recommendations that would afford occupants the best chance of surviving an emergency landing or accident (80 *Federal Register* 68599) (NARA 2015). The Rotorcraft Occupant Protection Working Group completed its initial task by performing a cost-benefit analysis of incorporating the existing protection standards in newly manufactured rotorcraft and providing a report of the results of this analysis to the ARAC on November 10, 2016.

[85] The NTSB issued these recommendations as a result of the Frisco accident and an accident involving an Airbus Helicopters EC130 B4 on March 6, 2015, in St. Louis, Missouri. For more information about the St. Louis accident, see case number CEN15FA164.

practicable. To encourage helicopter owners and operators to retrofit existing helicopters with a crash-resistant fuel system, the SAIB should also discuss the helicopter accidents cited in this report. (A-16-9)

Issue a special airworthiness information bulletin that is periodically updated to inform all helicopter owners and operators about available modifications to improve fuel system crashworthiness and urge that they be installed as soon as practicable. To encourage helicopter owners and operators to retrofit existing helicopters with a crash-resistant fuel system, the SAIB should also discuss the helicopter accidents cited in this report. (A-16-10)

On July 12, 2016, the FAA stated that it agreed with these recommendations. Regarding Safety Recommendation A-16-8, the FAA stated that it would work with EASA to validate the certification design changes of the CRFS for the affected helicopters. Regarding Safety Recommendations A-16-9 and -10, the FAA stated that it would use an SAIB to encourage the retrofit installation of the CRFS to all helicopter owners and operators.

On October 12, 2016, the NTSB classified Safety Recommendation A-16-8 "Open—Acceptable Response" pending the FAA's timely approval of the retrofit kits for AS350 B3e helicopters and similarly designed variants. Regarding Safety Recommendations A-16-9 and -10, the NTSB pointed out that these recommendations asked for similar, but separate, SAIBs. The NTSB explained that the intent of A-16-9 was to notify the owners and operators of affected helicopters about the availability of the CRFS retrofit kits and encourage their installation. The NTSB further explained that the intent of A-16-10 was to address concerns that owners and operators of other Part 27 and Part 29 helicopter models without a CRFS might not know that modifications were available to improve fuel system crash resistance for their particular helicopter model. As a result, the NTSB classified Safety Recommendations A-16-9 and -10 "Open—Acceptable Response" pending the issuance of the requested SAIBs.

Safety Recommendation A-16-11 asked EASA to take the same action requested in Safety Recommendation A-16-8. On June 7, 2016, EASA stated that it was working with Airbus Helicopters to "expedite the certification of a retrofittable design change to incorporate a crash-resistant fuel system" into the AS350 B3e helicopter. EASA also stated that it would prioritize the approval of retrofittable design changes for other similarly designed variants once Airbus Helicopters completed the development and applied for the certification of the design changes. On August 24, 2016, the NTSB classified Safety Recommendation A-16-11 "Open—Acceptable Response" pending EASA's approval of retrofit kits for these helicopters.

1.6.3.2 Analysis

The accident helicopter's fuel tank did not meet, and was not required to meet, the fuel system crash resistance standards of 14 *CFR* 27.952. Also, at the time of the accident, no retrofit options were available to improve fuel system crash resistance for the AS350 B3e and other AS350-series helicopters.

The video study for this accident estimated that the vertical speed at ground impact was about 58 ± 5 feet per second. For CRFS certification, section 27.952(a) requires a 50-foot vertical drop test of a fuel tank (with portions of the surrounding structure) that is filled with water to 80% of the normal capacity with no leakage. FAA AC 27-1B indicates that any fluid leakage or seepage 15 minutes after the drop occurred constitutes a test failure. According to basic kinematic equations, a 50-foot drop test would result in a fuel tank vertical impact velocity of about 57 feet per second. The vertical impact velocity observed in the surveillance video was similar to that of a CRFS certification drop test and, given this vertical impact velocity, a CRFS would perform better (by reducing fuel spillage) than the fuel system that had been installed in the accident helicopter. Thus, it is likely that substantially less fuel would have been released after impact if the helicopter had been equipped with a CRFS that met certification standards.

It is likely that the postcrash fire significantly decreased the pilot's chance of survival (due to his significant thermal lung injuries) and directly contributed to his death. It is also likely that the flight nurse in the left aft seat will experience life-long complications as a result of the severity of his thermal injuries (burns over 90% of his body) from this accident. The NTSB concludes that, if the helicopter had been equipped with a CRFS, the potential for thermal injuries to the occupants would have been reduced or eliminated.

1.6.4 Awareness of Helicopter Crashworthiness Standards

As stated in sections 1.6.2 and 1.6.3, the FAA improved helicopter crashworthiness standards by requiring (1) rotorcraft certificated after December 1989 to meet the emergency landing dynamic conditions defined in 14 *CFR* 27.561 and 27.562 or 29.561 and 29.562 and (2) rotorcraft certificated after November 1994 to meet the fuel system crashworthiness requirements of section 27.952 or 29.952. Thus, newly manufactured rotorcraft with type certificates approved before December 1989 are not subject to the improved occupant safety requirements for emergency landing conditions (including an increase in the downward load factor from 4 to 20 G), and newly manufactured rotorcraft with type certificates approved before November 1994 might not incorporate a CRFS.

The aircraft certification process is complex and might not be fully understood by some helicopter operators and customers (Smallhorn 2012). Specifically, the distinction between the aircraft type certificate date and manufacture date relative to the latest crashworthiness requirements might not be clear to those purchasing or leasing helicopters. For example, helicopter operators and customers might assume that a newly manufactured helicopter meets the latest FAA crashworthiness requirements, but this assumption might not be correct. As of November 2014, only about 15% of US-registered helicopters that were manufactured after 1994 had a CRFS (NTSB 2016). Also, the FAA estimated that, as of 2014, only 10% of all US-registered helicopters were fully compliant with the improved crashworthiness standards for seats (Roskop 2015). Further, a recent study of 22 helicopter air ambulance (HAA) accidents indicated that none of the helicopter models had fully satisfied the latest crashworthiness standards and that only 2 helicopter models had partially satisfied the standards (Boyd and Macchiarella 2016).

The NTSB spoke with multiple helicopter operators, contract specialists, manufacturers, pilots, and emergency medical service personnel who fly in helicopters to determine their awareness of the certification process for helicopter crashworthiness. The NTSB found that those with an extensive aviation background understood that most newly manufactured helicopters were not equipped with a CRFS or energy-absorbing seats (which meet the requirements of the

December 1989 regulations). For example, Air Methods, the largest US air medical helicopter operator, stated that its new helicopter purchases would focus on those helicopters designed with seats that met the improved crashworthiness requirements.[86] Also, as a result of the Frisco accident, the company stated that it would equip its AS350-series and EC130 B4 helicopter fleets with a CRFS as retrofit options became available.

However, the NTSB also found that those without an extensive aviation background were unaware that most newly manufactured helicopters were not required to meet the latest helicopter crashworthiness requirements. For example, one operator that was negotiating the terms of a contract to purchase a helicopter was not aware of the difference between the helicopter's type certificate date and manufacture date and, after becoming so aware, changed the terms of the contract to include the installation of energy-absorbing seats when they became available. Also, another operator, which purchased several new helicopters in 2012, did not know at that time that newly manufactured helicopters might not be designed to meet the most recent crashworthiness requirements. In September 2016, this operator stated that it would be requesting a meeting with the manufacturer to determine which crashworthiness requirements the purchased helicopters met.

A number of factors can influence purchasing and leasing decisions for helicopters, including budget constraints, operational requirements, configuration, potential payload and range, and equipage (NTSB 1988). In addition, challenges that operators in the HAA industry might have in introducing helicopters with improved crashworthiness standards into their fleet include increased cost and weight and a resultant reduction in payload and range, which could affect the suitability of the helicopter for its intended use (Boyd and Macchiarella 2016). Nonetheless, because of the distinctions involved with the helicopter certification process, helicopter operators and customers might not be making fully informed purchasing and leasing decisions regarding a helicopter's crashworthiness.

Guidelines identifying the systems that would meet the latest helicopter crashworthiness standards could result in an increased awareness among helicopter purchasers, leasers, contracting personnel, and users about the availability of a CRFS and energy-absorbing seats and the lack of these safety features in many existing and newly manufactured helicopters.[87] Such awareness is important given that helicopters in the US fleet have a long life span. For example, according to the General Aviation Manufacturers Association's *2014 General Aviation Statistical Databook & 2015 Industry Outlook*, single-engine turbine helicopters in the US fleet in 2013 had an average age of 22.3 years.

Because guidelines would not depend on a regulatory process, they could be flexible as technological advancements are made. The guidelines could also be implemented faster than regulations. For example, the NTSB recognized the safety benefit of helicopter fuel tank

[86] In its party submission for this accident, Air Methods stated that it is the "largest provider of air medical emergency transport services" in the United States.

[87] As stated in section 1.6.2.1, there was insufficient evidence from this accident to determine whether improved medical crewmember seats would have reduced the blunt force trauma injuries to the flight nurse in the right aft seat. However, seats comprise a portion of a helicopter's crashworthiness, and seats that meet the improved dynamic emergency landing condition requirements should provide better protection to occupants compared with seats meeting the previous requirements.

crashworthiness in the 1980s and issued safety recommendations to the FAA, but the amendments to Part 27 and 29 airworthiness standards to require a CRFS for newly certificated rotorcraft did not become effective until late 1994.[88]

In addition, guidelines aimed at increasing awareness about available helicopter crashworthiness systems could increase inquiries to manufacturers regarding the availability of these systems. Manufacturers would then recognize that the availability of improved crashworthiness systems is a factor in helicopter purchase decisions, which would thus increase the demand for these systems (an approach to production development based on market forces). As a result, the guidelines could encourage helicopter manufacturers to develop and equip their previously type-certificated helicopters with systems meeting the latest crashworthiness standards. Such changes could be accomplished as safety improvements are identified and developed rather than after regulations become effective. Finally, guidelines could encourage manufacturers to design and produce approved retrofit kits to enhance helicopter crashworthiness, such as the CRFS retrofit kits that Airbus Helicopters developed for existing AS350 B3e helicopters (as referenced in EASA's response to Safety Recommendation A-16-11).

On February 13, 2017, the FAA released data showing reductions in the US helicopter accident rate and fatal accident rate, crediting education, technology, and safety improvements for the reductions.[89] Further reductions in the fatal accident rate could be achieved with increased awareness of equipment to enhance helicopter crashworthiness.

Some of the professional organizations within the HAA industry develop standards and guidance for use by the industry, including the Association of Critical Care Transport (ACCT), which, in October 2016, released its C*ritical Care Transport Standards*.[90] These standards included vehicle configuration and equipment necessary for patient care but did not include information regarding the differing levels of crashworthiness protection for HAA staff and patients in newly certificated helicopters versus newly manufactured helicopters. However, both the *Critical Care Transport Standards* and the ACCT's website indicated that the document's recommendations would continue to evolve and that the organization was committed to "ongoing dialogue with the medical transport community, healthcare systems, policy makers, and payors...to gather input and work to further strengthen and develop the Standards."

Other professional organizations representing stakeholders in the HAA industry include the Association of Air Medical Services (AAMS) and the Air Medical Operators Association (AMOA). The AAMS represents the air and ground medical transport community, including medical transport service providers, suppliers, and individuals, and AMOA represents a number

[88] These safety recommendations included A-85-69 and -71, which were issued on October 1, 1985, and were classified "Closed—Acceptable Action" on June 7, 1995, after the FAA amended Parts 27 and 29.

[89] The FAA indicated that, in 2016, the US helicopter accident rate had decreased to 3.19 accidents per 100,000 flight hours compared with 3.67 accidents in 2015. The FAA also indicated that the fatal accident rate was 0.51 accidents per 100,000 flight hours in 2016 compared with a rate of 0.52 accidents per 100,000 flight hours in 2015. In addition, the FAA stated that it was working with industry representatives to prevent injuries and postcrash fires through the voluntary installation of "life-saving equipment" on newly manufactured helicopters.

[90] ACCT comprises air and ground critical care transport providers, business organizations, and associations. According to its website, ACCT is "committed to ensuring that critically ill and injured patients have access to the safest and highest quality critical care transport system possible" (https://www.acctforpatients.org, accessed February 2, 2017).

of Part 135 HAA operators. Thus, the AAMS and AMOA are in an ideal position to support an effort led by the ACCT to develop safety guidelines that could be disseminated to those who purchase, lease, or contract for helicopters.

The NTSB concludes that those who purchase, lease, or contract for helicopter services and those who operate or fly aboard helicopters as part of their job are likely unaware that the designs of most existing and newly manufactured helicopters do not include the improved crashworthiness standards required of newly certificated helicopters, which could compromise occupant protection if an accident were to occur. Therefore, the NTSB recommends that the ACCT, in collaboration with the AAMS and AMOA, establish a working group to develop and distribute guidelines, for those who purchase, lease, or contract for helicopters, regarding the equipment and systems that would enhance the helicopters' crashworthiness, including, at a minimum, a CRFS and energy-absorbing seats. The NTSB further recommends that the AAMS and AMOA work with the ACCT to establish a working group to develop and distribute guidelines, for those who purchase, lease, or contract for helicopters, regarding the equipment and systems that would enhance the helicopters' crashworthiness, including, at a minimum, a CRFS and energy-absorbing seats.

Although the crashworthiness of helicopters was the focus of the survival factors aspect of this accident, the NTSB recognizes that guidelines for making helicopter purchasing and leasing decisions could also include operational safety equipment. Appendix B includes examples of NTSB recommendations addressing helicopter operational safety. In addition, appendix B provides examples of guidelines identifying recommended practices for improving safety that have been successful in other transportation industries.

1.7 Organizational Information

Air Methods Corporation was established in 1980 as a commercial on-demand air taxi operator specializing in HAA services. Air Methods is headquartered at Centennial Airport in Englewood, Colorado. Air Methods operates 300 bases that serve 48 states (including Alaska), and its fleet of 450 aircraft consists primarily of Airbus and Bell helicopters. At the time of the accident, the company employed 1,293 helicopter pilots, 4 of whom were assigned to the Frisco base (including the accident pilot).

1.7.1 Safety Program and Culture

The Air Methods *General Operations Manual* provided information about the company's safety program.[91] The manual indicated that Air Methods was committed to attaining "the highest level of safety" in accomplishing the company's mission. The manual also indicated the core elements that comprised Air Methods' safety program, which included the company's safety

[91] The Air Methods *General Operations Manual* also provided information about the company's operational risk assessment program. The manual indicated that this program assists pilots "in identifying, assessing, and managing risks and then ensuring that they are mitigated, deferred, or accepted." Pilots are required to use the company's risk assessment tool before deciding whether to accept or decline a flight assignment.

management system (SMS) policy manual and accident, incident, damage, malfunction, and operations reports (AIDMOR).

When fully staffed, the Air Methods safety department comprised a vice president of safety and risk management, a director of flight safety, six regional safety directors, a flight operational quality assurance (FOQA) manager, an "excellence through quality" manager, an aviation safety action program/maintenance safety action program (ASAP/MSAP) manager, and 156 field safety representatives. As of October 2015, Air Methods' vice president of aviation services was the acting vice president of safety and risk management. (The vice president of safety and risk management at the time of the accident left Air Methods in September 2015 for a position at another company.) He stated that other positions in the safety department were vacant at that time (October 2015), including the director of flight safety and two regional safety director positions.[92]

During postaccident interviews, Air Methods personnel indicated that the company participated in several safety programs (in addition to SMS, AIDMOR, ASAP/MSAP, and FOQA), including the line operational safety audit program, the internal evaluation program, the AlertLine application, and postaccident and incident reporting.[93] Pilots could also communicate safety-related information with management in person or via e-mail or telephone.

The safety culture at Air Methods was another topic discussed during postaccident interviews. The chief pilot stated his belief that "safety is in the front of our mind" and that "safety has to start from the top." Also, the vice president of safety and risk management at the time of the accident stated that "with 300 [Air Methods] bases, you would have…maybe 600 [safety] cultures that day, if you figure you've got the shift change coming in every 12 hours." This vice president further stated that one of his "major pain points" was that it could sometimes be difficult to communicate the "corporate expectation all the way out into the field on a consistent basis." He added that this situation would not have compromised safety because "everybody out in the field…based on their experience and their professionalism, did a good job."

1.7.2 Analysis

Organizational culture can be defined as "the values, norms, beliefs, and practices that govern how an institution functions. At the most basic level, organizational culture defines the assumptions that employees make as they carry out their work" (NASA 2003). The NTSB considered whether the organizational culture at Air Methods might have affected safety and led to procedural noncompliance on the day of the accident, especially given that the AS350 B3e incident in Temple, Texas (which occurred about 1 year before the accident in Frisco), involved a

[92] In January 2017, Air Methods' director of operations reported that the director of flight safety position was filled in January 2016 and that the vice president of safety and risk management position was filled in February 2016. The director of operations also reported that the vice president of safety and risk management position became vacant again in December 2016. On March 17, 2017, Air Methods' director of operations reported that the company had recently hired a new vice president of safety and risk management.

[93] The Air Methods *SMS Policy Manual* stated the following regarding the AlertLine application: "If working with a supervisor or manager does not resolve issues or concerns, employees are encouraged to report issues and concerns – without reprisal – using the AlertLine application."

helicopter operated by Air Methods and a pilot who likely did not return the yaw servo hydraulic switch to the "ON" position.

Air Methods had an established safety program in place at the time of the accident. The company's SMS, which was implemented in 2009, reached level 4 compliance—the final level of SMS maturity—in May 2013.[94] Although there were challenges with the Air Methods organization being spread across 300 bases throughout the United States, postaccident interviews demonstrated a commitment from management and staff to adhere to the policies and procedures outlined in the company's safety program. Also, postaccident interviews with Air Methods personnel, including line pilots, indicated that safety was important and not compromised, and pilots reported using checklists and following procedures on a consistent basis.

After the Frisco accident, several managers in the Air Methods safety department left the company for positions at other organizations. However, according to postaccident interviews, these departures were in process before the accident and were not a result of the accident. Also, none of the managers who left Air Methods were directly involved with operations at the Frisco base.

Some of the Air Methods personnel interviewed after the accident were not aware of the Airbus Helicopters safety information notice related to the yaw servo hydraulic check, which emphasized the importance of completing the final step of the check by returning the yaw servo hydraulic switch to the "ON" position (see section 1.3.5.4). The notice was issued 4 months after the Albuquerque accident; 2 months after the Temple, Texas, incident; and more than 10 months before the Frisco accident.[95] Although it is possible that pilots could learn about the information provided in Airbus Helicopters' safety information notices and SBs during recurrent training, there was no formal process for distributing this information to pilots. However, as previously stated, the accident pilot was reported to have always used the checklist when performing the steps of the yaw servo hydraulic check and was reportedly aware of the risk of taking off without restoring hydraulic system pressure to the yaw load compensator. Other comments about the pilot indicated that he was safety conscious and risk adverse and that he followed procedures.[96]

The NTSB could not determine why the pilot did not complete the yaw servo hydraulic check or perform a hover check before takeoff on the day of the accident. However, no evidence

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[94] The FAA's *Safety Management System (SMS) Implementation Guide*, dated June 1, 2010, stated the following regarding level 4, the continuous improvement level: "Processes have been in place and their performance and effectiveness has been verified. The complete safety assurance process, including continuous monitoring and the remaining features of the other SRM [safety risk management] and safety assurance processes are functioning. A major objective of a successful SMS is to attain and maintain this continuous improvement status for the life of the organization."

[95] In addition, as previously stated, Air Methods did not perform a risk assessment for Airbus Helicopters SB No. AS350-67.00.64 before the accident. This nonmandatory SB, which addressed the incorporation of a "HYD2" light on the caution and warning panel for dual-hydraulic AS350-series helicopters, was issued about 4 months before the accident.

[96] Because Air Methods pilots typically fly without a second pilot (except during training, when procedural compliance would be expected), the accident pilot's routine compliance with procedures could not be determined.

indicated that Air Methods compromised safety or that its organizational culture influenced the pilot's actions during the accident flight.

1.8 Onboard Image Recorder

The helicopter was equipped with an Appareo Vision 1000 onboard image recorder, serial number unknown. The Appareo Vision 1000 device is a small self-contained image, audio, and data recorder. The device, which is typically mounted in the overhead of an aircraft's cockpit, records interior cockpit images at a rate of four times per second and can record two audio tracks that are synchronized with the image data.[97] The device also contains a GPS receiver for satellite-based time, position, altitude, and speed data and a self-contained, real-time inertial measuring unit that provides three-axis accelerations and pitch, roll, and yaw data.

The Appareo device records data on an external removable secure digital (SD) memory card that retains about the last 2 hours of image and audio data and about the last 100 hours of parametric data. The device is also equipped with an internal NVM module that is minimally protected against impact and fire. The NVM module contains the same data stored on the SD memory card.

The Appareo device on the helicopter was connected to the battery through the master battery switch. The device would begin recording data anytime that the battery switch was turned on, with a new file created for every electrical power application.

Postaccident examination of the helicopter's Appareo device showed that the device sustained extensive heat damage. Figure 6a shows the condition of the Appareo device upon arrival at the NTSB's vehicle recorders laboratory, and figure 6b shows an exemplar Appareo Vision 1000 onboard image recorder for comparison purposes. The SD memory card was removed from the Appareo device. The silicon memory device (internal to the SD card) was cracked and fractured throughout, so data recovery from the SD card was not possible. The Appareo device's internal NVM module was then removed, and the two NVM chips were removed from the internal memory device chassis. One chip (referred to as NVM chip 1) exhibited bubbling on, and cracking along, its plastic packaging surface. The other chip (referred to as NVM chip 2) exhibited heavy bubbling on its plastic packaging surface. The bubbling and cracking were indicative of high-temperature heat damage.

[97] During the wreckage examination, the Appareo device was found installed on the roof of the cabin.

Figure 6a. Postaccident condition of onboard image recorder.

Figure 6b. Exemplar Appareo Vision 1000 onboard image recorder.

X-ray images of both NVM chips revealed a region of broken bond wires in the upper left portion of NVM chip 1 and no visible defects in NVM chip 2. A binary readout attempt of NVM chip 2 was performed but failed; an error message that is typically associated with failures due to internal damage to the chip was displayed. No further attempts were made to read out either NVM chip.

The NTSB provided the NVM chips to the Integrated Electronics Engineering Center at the State University of New York at Binghamton. A physical analysis report by the center characterized the possibility of recovery data from each chip as "poor." In addition, a second report from the center noted that NVM chip 2 was extensively damaged, with the most severe damage likely a result of the chip's exposure to high-temperature fire.

In addition, Air Methods provided the NTSB with historical data that had been collected from the accident helicopter for use in a flight data monitoring (FDM) program. These data consisted of 27 files of parametric data; one of the files had a structural problem, resulting in 26 files for analysis.[98] The NTSB intended to use the data to determine the frequency of hover checks at 91CO and the initial direction of takeoff from 91CO. However, the NTSB was not able to make these determinations because the quality of the data was poor. Specifically, there were dropouts and fluctuations of GPS information and pitch and roll parameters, some of the altitude data were well below ground elevation, and the derived altitude above the ground was discontinuous. Data plots, animations, and replays confirmed the issues with the quality of the data. Appareo indicated that these issues might have occurred because the GPS signal was intermittent (likely due to an antenna location and/or connection issue) and the pitch parameter was not calibrated.

1.8.1 Previous Related Safety Recommendations

On May 6, 2013, the NTSB issued Safety Recommendations A-13-12 and -13 to the FAA, which stated the following:[99]

> Require the installation of a crash-resistant flight recorder system on all newly manufactured turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with a flight data recorder and a cockpit voice recorder and are operating under 14 *Code of Federal Regulations* Parts 91, 121, or 135. The crash-resistant flight recorder system should record cockpit audio and images with a view of the cockpit environment to include as much of the outside view as possible, and parametric data per aircraft and system installation, all as specified in Technical Standard Order C197, 'Information Collection and Monitoring Systems.' (A-13-12)

[98] Image and audio data were not part of the company's FDM program.

[99] These recommendations were issued as part of the NTSB's investigation of the 2011 accident involving an Air Methods Eurocopter AS350 B2 in Mosby, Missouri. The helicopter did not have, and was not required to have, a crash-resistant flight recorder installed. In its final report on the accident, the NTSB determined that a flight recorder system that captured cockpit audio, images, and parametric data would have enabled investigators to reconstruct the final moments of the flight and determine why the pilot did not successfully enter an autorotation when the engine lost power due to fuel exhaustion (NTSB 2013).

> Require all existing turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with a flight data recorder or cockpit voice recorder and are operating under 14 *Code of Federal Regulations* Parts 91, 121, or 135 to be retrofitted with a crash-resistant flight recorder system. The crash-resistant flight recorder system should record cockpit audio and images with a view of the cockpit environment to include as much of the outside view as possible, and parametric data per aircraft and system installation, all as specified in Technical Standard Order C197, 'Information Collection and Monitoring Systems.' (A-13-13)[100]

These safety recommendations are the latest in a series of recommendations that the NTSB has issued since 1999 regarding the need for crash-resistant flight recorder systems on new and existing aircraft that are not already required to have such recorders, as shown in table 4.

Table 4. Safety recommendations preceding A-13-12 and -13.

Recommendation number	Outcome
A-99-60	Classified "Closed—Superseded." Superseded by A-03-64 on December 22, 2003.
A-03-62	Classified "Closed—Unacceptable Action/Superseded." Superseded by A-09-9 on February 9, 2009.
A-03-63	Classified "Closed—Unacceptable Action" on October 27, 2009.
A-03-64	Classified "Closed—Unacceptable Action/Superseded." Superseded by A-09-10 on February 9, 2009.
A-03-65	Classified "Closed—Unacceptable Action/Superseded." Superseded by A-09-11 on February 9, 2009.
A-09-9	Classified "Closed—Unacceptable Action" on June 11, 2012.
A-09-10	Reiterated on June 9, 2011. Classified "Closed—Unacceptable Action" on June 11, 2012.
A-09-11	Reiterated on June 9, 2011. Classified "Closed—Unacceptable Action" on June 11, 2012.

Note: A-99-60 was issued as part of the investigation of DCA98MA002. A-03-62 through -65 were issued as part of several investigations, including DCA03MA008. A-09-09 through -11 were issued as part of the investigation of LAX07MA231A and LAX07MA231B. A-09-10 and -11 were reiterated as part of the investigation of ANC10MA068.

Regarding Safety Recommendations A-13-12 and -13, on August 1, 2013, the FAA stated that it had responded to similar safety recommendations, including A-09-9, -10, and -11, and that the position stated in its last two letters to the NTSB regarding those recommendations (dated February 15, 2011, and January 27, 2012) had not changed. The FAA repeated that it did not intend to mandate crash-resistant flight recording systems on all turbine-powered, nonexperimental, nonrestricted-category aircraft because (1) the rulemaking environment required new regulations to have "a positive economic cost-benefit to society"; (2) the FAA could not "place a quantitative benefit" for mandating crash-resistant flight recording system equipage; and (3) data from crash-resistant flight recording systems were primarily used for risk identification, evidence-based decision-making, enhanced training scenarios, risk mitigation, and remedial action effectiveness.

On December 10, 2013, the NTSB stated that it continues to investigate accidents in which crash-resistant flight recorder systems would have provided vital, detailed information regarding the circumstances of the accidents, but the FAA has not yet required the installation of such

[100] TSO-C197 contains technical standards for image recorder systems used on smaller aircraft, including provisions that protect recorded data from crash impact damage and postcrash fire damage. The onboard image recorder installed on the helicopter involved in the Frisco accident did not comply, and was not required to comply, with TSO-C197.

systems. The NTSB further stated that the lack of crash-resistant flight recorder systems in aircraft remains an important safety issue and, as a result, classified Safety Recommendations A-13-12 and -13 “Open—Unacceptable Response.”

On May 23, 2016, the FAA responded that crash-resistant flight recorder systems would provide a visual account of crew actions and parametric data to use for accident investigation but indicated that it still did not intend to mandate such systems on all turbine-powered, nonexperimental, nonrestricted-category aircraft because of significant costs and the limited ability to assess benefits.[101] The FAA stated that, because rulemaking to mandate such recorders on these aircraft was not a viable option, the agency adopted a position of “promoting and incentivizing” the voluntary equipage of image recorders through the use of the following three documents:

- TSO-C197, which provides the minimum operational performance standards for recording systems, including audio and image recorders, and standardizes the design and production certification requirements for equipment manufacturers to streamline aircraft installation and integration;
- “Helicopter Air Ambulance, Commercial Helicopter, and Part 91 Helicopter Operations, Final Rule” (79 *Federal Register* 9931), which requires (in section 135.607) that helicopters conducting air ambulance operations be equipped with FDM systems by April 23, 2018 (NARA 2014); and
- “Helicopter Flight Data Monitoring – Industry Best Practices,” which, according to the FAA, is an “excellent” resource for the rotorcraft community and has information that can be applied generally to airplane operations, including incentives for the voluntary equipage of FDM systems.

On August 11, 2016, the NTSB stated it considered the FAA’s framework for “promoting and incentivizing” the voluntary equipage of image recorders and determined that the issuance of TSO-C197 was a positive action but did not satisfy the intent of the recommendations. The NTSB also determined that the final rule did not address all turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with flight data recorders or cockpit voice recorders and that the requirement addressed in the final rule would not promote the voluntary equipage of image recorders on those aircraft. In addition, the NTSB determined that, although the “Helicopter Flight Data Monitoring – Industry Best Practices” publication provided beneficial guidance for establishing and operating an FDM program, the publication did not promote such a program. The NTSB further noted that it would be unlikely that those not involved with helicopter operations would refer to this document.

The NTSB stated that the FAA, as part of its evaluation of these recommendations, should review the safety improvements that have been implemented because of the information learned from recorder data. Specifically, for some improvements, safety risks would not have been identified, or would not have been sufficiently understood to develop a mitigation, without the recorder data. The NTSB also stated that such a review should acknowledge the number of accidents that the NTSB investigated in which the probable cause could not be determined because

[101] The FAA had previously responded to these recommendations in an August 14, 2014, letter, and the NTSB response to this FAA letter was dated November 17, 2014.

of the lack of recorder data. The NTSB believed that such information would be important for developing the needed cost-benefit analyses that the FAA stated was necessary to justify rulemaking for crash-resistant flight recorder systems. The NTSB indicated that Safety Recommendations A-13-12 and -13 remained classified "Open—Unacceptable Response."

1.8.2 Analysis

The NTSB has investigated some accidents in which aircraft had been voluntarily equipped with crash-resistant flight recorder systems, and the data retrieved from those recorders significantly aided the investigations. However, the NTSB has also investigated some accidents in which aircraft were voluntarily equipped with flight recorders that did not comply with TSO-C197, as requested in Safety Recommendations A-13-12 and -13. In many of the cases involving flight recorders that did not comply with TSO-C197, including the Frisco accident, the NTSB was unable to recover data due to impact and postcrash fire damage. The inability to recover such data precluded the identification of potential safety issues that might not be detectable through other means. For example, as a result of the inability to recover data from the Appareo device that was installed on the helicopter involved in the Frisco accident, the NTSB could not determine possible reasons that the pilot did not complete the last step of the yaw servo hydraulic check or perform a hover check. Also, the NTSB could not determine the duration of the pilot's full right pedal input before ground impact, his cyclic input, and any annunciations on the caution and warning panel.

Most aircraft involved in the NTSB's investigations do not have a crash-resistant flight recorder, which can affect the agency's ability to fully investigate the circumstances leading to an event. For example, the lack of available data significantly hindered the NTSB's investigation of the November 10, 2013, accident involving a Mitsubishi MU-2B-25 that impacted wooded terrain while maneuvering near Owasso, Oklahoma. The NTSB found that, if a crash-resistant flight recorder system had been required and installed on the airplane, recorded video images could have shown where the pilot's attention was directed during the problems (including a left engine shutdown) that he reported to air traffic control, his interaction with the airplane controls and systems, and the status of cockpit switches and instruments. A crash-resistant flight recorder system could also have provided information about the engine's operating parameters and the airplane's motions, which would have allowed the NTSB to determine the reasons for the left engine shutdown and evaluate the pilot's recognition of and response to an engine problem.[102]

Although many of the events leading to the Frisco accident could be determined from surveillance videos, such videos are not available for most NTSB investigations, and surveillance videos do not contain the audio, image, and parametric data provided by a crash-resistant flight recorder system. Also, this accident demonstrated that important data might not be recoverable from a flight recorder system that does not comply with the crash-resistance requirements of TSO-C197 if the system was damaged by impact forces and/or fire. The NTSB concludes that data to better understand the safety issues involved in this accident could likely have been recovered from a flight recorder system that complied with the provisions of FAA TSO-C197. As a result, the NTSB reiterates Safety Recommendations A-13-12 and -13.

[102] For more information about this accident, see case number CEN14FA046. As a result of the findings from that investigation, the NTSB reiterated Safety Recommendation A-13-13 on October 23, 2014.

2. Conclusions

2.1 Findings

1. The helicopter was properly certificated, equipped, and maintained in accordance with federal regulations. None of the available evidence indicated any preimpact structural, engine, or system failures.

2. The pilot was properly certificated and qualified in accordance with federal regulations. Pilot fatigue and the pilot's medical conditions and prescribed medications were not factors in this accident.

3. The wind conditions at the time of the accident would not have prevented the pilot from maintaining yaw control of the helicopter.

4. The pilot most likely did not return the yaw servo hydraulic switch to its correct ("ON") position before takeoff, resulting in a lack of hydraulic pressure to the tail rotor servo control and the yaw load compensator accumulator.

5. A lack of hydraulic boost to the pedals, resulting in significantly increased pedal loads, was the most likely cause of the loss of tail rotor control, which led to the left yaw that occurred simultaneously with takeoff.

6. A salient alert for insufficient hydraulic pressure in the tail rotor hydraulic circuit could have cued the pilot to the incorrect configuration of the tail rotor hydraulic circuit, the lack of hydraulic boost to the pedal controls, and the resulting increased pedal loads.

7. Although not required to do so, Air Methods did not aggressively take action to comply with Airbus Helicopters' Service Bulletin No. AS350-67.00.64, which called for installing a flashing light on the cockpit caution and warning panel to alert pilots that the yaw servo hydraulic switch was in the incorrect position; if this nonmandatory service bulletin had been complied with, the pilot might have noticed that the switch was not in the correct ("ON") position before takeoff.

8. The design of Airbus Helicopters dual-hydraulic AS350-series helicopters did not account for the possibility of pilot error in configuring the tail rotor hydraulic circuit or assessing the functionality of the yaw load compensator, and efforts to address these safety issues have thus far been insufficient.

9. Despite the significantly increased pedal loads, the pilot continued the takeoff to climb the helicopter above nearby obstacles and gain forward airspeed to counter the left yaw rotation, but his efforts were unsuccessful.

10. If the pilot had performed a hover check, he would have identified the pedal control anomaly at an altitude that could have afforded a safe landing on the helipad.

11. The flight nurse in the left aft seat had likely been restrained in his seat and was likely ejected from the helicopter with his seat during the accident sequence.

12. The impact forces of this accident were survivable for the helicopter occupants.

13. If the helicopter had been equipped with a crash-resistant fuel system, the potential for thermal injuries to the occupants would have been reduced or eliminated.

14. Those who purchase, lease, or contract for helicopter services and those who operate or fly aboard helicopters as part of their job are likely unaware that the designs of most existing and newly manufactured helicopters do not include the improved crashworthiness standards required of newly certificated helicopters, which could compromise occupant protection if an accident were to occur.

15. Data to better understand the safety issues involved in this accident could likely have been recovered from a flight recorder system that complied with the provisions of Federal Aviation Administration Technical Standard Order C197, "Information Collection and Monitoring Systems."

2.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was Airbus Helicopters' dual-hydraulic AS350 B3e helicopter's (1) preflight hydraulic check, which depleted hydraulic pressure in the tail rotor hydraulic circuit, and (2) lack of salient alerting to the pilot that hydraulic pressure was not restored before takeoff. Such alerting might have cued the pilot to his failure to reset the yaw servo hydraulic switch to its correct position during the preflight hydraulic check, which resulted in a lack of hydraulic boost to the pedal controls, high pedal forces, and a subsequent loss of control after takeoff. Contributing to the accident was the pilot's failure to perform a hover check after liftoff, which would have alerted him to the pedal control anomaly at an altitude that could have allowed him to safely land the helicopter. Contributing to the severity of the injuries was the helicopter's fuel system, which was not crash resistant and facilitated a fuel-fed postcrash fire.

3. Recommendations

3.1 New Recommendations

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

To the Federal Aviation Administration:

Require that existing Airbus Helicopters dual-hydraulic AS350-series helicopters be equipped with a visual and an aural alert for the loss of hydraulic boost to the pedal controls, which would result in increased pedal loads. (A-17-8)

To Airbus Helicopters:

For newly manufactured dual-hydraulic AS350-series helicopters, assess and implement changes to the dual hydraulic system that would both ensure pedal control hydraulic assistance and mitigate the possibility of pilot error during any check of the hydraulic system. (A-17-9)

For existing dual-hydraulic AS350-series helicopters, assess and implement changes to the dual hydraulic system that would both ensure pedal control hydraulic assistance and mitigate the possibility of pilot error during any check of the hydraulic system. (A-17-10)

To the Federal Aviation Administration and the European Aviation Safety Agency:

After the actions requested in Safety Recommendation A-17-10 are completed, require operators of Airbus Helicopters dual-hydraulic AS350-series helicopters to incorporate changes to the dual hydraulic system to both ensure pedal control hydraulic assistance and mitigate the possibility of pilot error during any check of the hydraulic system. (A-17-11)

To the Association of Critical Care Transport:

In collaboration with the Association of Air Medical Services and the Air Medical Operators Association, establish a working group to develop and distribute guidelines, for those who purchase, lease, or contract for helicopters, regarding the equipment and systems that would enhance the helicopters' crashworthiness, including, at a minimum, a crash-resistant fuel system and energy-absorbing seats. (A-17-12)

To the Association of Air Medical Services and the Air Medical Operators Association:

Work with the Association of Critical Care Transport to establish a working group to develop and distribute guidelines, for those who purchase, lease, or contract for

> helicopters, regarding the equipment and systems that would enhance the helicopters' crashworthiness, including, at a minimum, a crash-resistant fuel system and energy-absorbing seats. (A-17-13)

3.2 Previously Issued Recommendations

As a result of this accident investigation, the National Transportation Safety Board previously issued the following recommendations:

To the Federal Aviation Administration:

> Once Airbus Helicopters completes development of a retrofit kit to incorporate a crash-resistant fuel system into AS350 B3e and similarly designed variants, prioritize its approval to accelerate its availability to operators. (A-16-8) (Open—Acceptable Response)

> Issue a special airworthiness information bulletin (SAIB) informing all owners and operators of AS350 B3e and similarly designed variants of the availability of a crash-resistant fuel system retrofit kit and urging that it be installed as soon as practicable. To encourage helicopter owners and operators to retrofit existing helicopters with a crash-resistant fuel system, the SAIB should also discuss the helicopter accidents cited in this report. (A-16-9) (Open—Acceptable Response)

> Issue a special airworthiness information bulletin that is periodically updated to inform all helicopter owners and operators about available modifications to improve fuel system crashworthiness and urge that they be installed as soon as practicable. To encourage helicopter owners and operators to retrofit existing helicopters with a crash-resistant fuel system, the SAIB should also discuss the helicopter accidents cited in this report. (A-16-10) (Open—Acceptable Response)

To the European Aviation Safety Agency:

> Once Airbus Helicopters completes development of a retrofit kit to incorporate a crash-resistant fuel system into AS350 B3e and similarly designed variants, prioritize its approval to accelerate its availability to operators. (A-16-11) (Open—Acceptable Response)

3.3 Previously Issued Recommendations Reiterated in This Report

The National Transportation Safety Board reiterates the following recommendations to the Federal Aviation Administration:

> Require the installation of a crash-resistant flight recorder system on all newly manufactured turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with a flight data recorder and a cockpit voice recorder and are operating under 14 *Code of Federal Regulations* Parts 91, 121, or 135. The crash-resistant flight recorder system should record cockpit audio and images with

a view of the cockpit environment to include as much of the outside view as possible, and parametric data per aircraft and system installation, all as specified in Technical Standard Order C197, 'Information Collection and Monitoring Systems.' (A-13-12)

Require all existing turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with a flight data recorder or cockpit voice recorder and are operating under 14 *Code of Federal Regulations* Parts 91, 121, or 135 to be retrofitted with a crash-resistant flight recorder system. The crash-resistant flight recorder system should record cockpit audio and images with a view of the cockpit environment to include as much of the outside view as possible, and parametric data per aircraft and system installation, all as specified in Technical Standard Order C197, 'Information Collection and Monitoring Systems.' (A-13-13)

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

T. BELLA DINH-ZARR
Acting Chairman

ROBERT L. SUMWALT, III
Member

CHRISTOPHER A. HART
Member

EARL F. WEENER
Member

Adopted: March 28, 2017

Board Member Statements

Acting Chairman Robert L. Sumwalt, III, filed the following concurring statement on April 4, 2017[103]:

In this tragic accident, the investigation concluded the pilot did not return the yaw servo hydraulic switch to the correct ("ON") position, ultimately leading to the pilot's loss of control after takeoff.

Error identified. Accident solved, right?

Not so fast.

If the purpose of accident investigation were to apportion blame, lay fault, or point fingers, one could reasonably arrive at the conclusion that the pilot "caused" the accident. After all, it was his error that ultimately led to the crash. But the purpose of an NTSB investigation isn't to find fault. Instead, the purpose is to identify the underlying factors that led to, or contributed to, the accident so that corrective actions can be taken to avoid future accidents. If the investigation only focuses on the obvious human error, we miss valuable accident prevention opportunities.

I believe this investigation thoroughly identified the underlying factors. The Board also issued solid recommendations aimed at correcting those underlying factors with the goal of preventing similar accidents.

We had an enlightening debate in the Board Meeting regarding where the pilot's error should be listed in the probable cause. The probable cause statement, as proposed by the investigative staff, listed the pilot's error as the foremost cause of the accident, followed by the lack of salient alerting as a contributing factor. However, the Board believed that this statement deemphasized the point that the pilot did not make these errors in a vacuum. After all, he was well-aware of the hazards associated with attempting to takeoff with the switch in the "OFF" position. He was described as being a very conscientious pilot who rigorously followed procedures. The fact that there had been four accidents (including this one) attributed to the same error provided a compelling case for believing it was more than simply "pilot error."

A deeper dive into the underlying factors revealed that Airbus Helicopters developed a preflight test procedure that called for completely removing hydraulic boost to the tail rotor. If the last step of that procedure was inadvertently omitted – as is believed to be the case in this accident – hydraulic boost would not be restored, creating the opportunity for take off in potentially perilous configuration. But, instead of alerting the pilot that this last critical step had been omitted, Airbus Helicopters failed to provide pilots with salient alerting. In fact, in my opinion, the system set a trap: if hydraulic pressure was lost to either of the two hydraulic systems through means other than the preflight test procedure, an alert light would illuminate on a cockpit display; if tail rotor

[103] Board Member T. Bella Dinh-Zarr was acting chairman of the NTSB when the accident report was adopted on March 28, 2017. Effective March 30, 2017, Board Member Robert L. Sumwalt, III is acting chairman.

hydraulic pressure was deliberately depleted as part of the preflight check, however, no such salient alerting would be provided to the pilot.

There is little doubt in my mind that the pilot committed an error. However, the circumstances created by Airbus Helicopters were the ultimate factors that actually set the stage for the pilot's failure to return the switch to the correct ("ON") position, and failure to catch the error before takeoff. I am pleased that the Board focused on these underlying factors and did not simply point the finger of blame at the pilot. If you design a system with traps, sooner or later, it will snare someone. Unfortunately, on July 3, 2015, this pilot and two flight nurses were caught in that trap.

Members Hart and Weener joined in this statement.

Member Earl F. Weener filed the following concurring statement on April 6, 2017:

I submit this statement in concurrence with the excellent report wherein staff determined the causes of this tragic crash and suggested curative strategies to prevent similar events from occurring in the future. In my years at the Board, the most often debated portion of any report seems to be the statement of probable cause. In fact, one of the most fundamental questions we face as an agency is how we define that very thing, probable cause. In my opinion, probable cause is best described as an accumulation of facts gathered through diligent investigation which, when coupled with solid scientific principles and sound deductive reasoning, led our highly educated, extensively experienced staff to reach a conclusion regarding the series of events leading to an accident.

Our investigators face real challenges in their efforts to find out how a crash occurred. Too frequently, they are hindered by the lack of crash resistant recorders. Other times, vehicle, aircraft, or vessel operators decline or are unable to participate in the investigation, preventing the investigators from accessing important, firsthand evidence. Witness statements submitted with absolute sincerity must be examined with the understanding that fear, trauma, and the urge to protect fellow operators who may be well-known to a witness can color perspective. Even recovering wreckage, whether it be at the top of a remote mountain or on the ocean floor, poses its own difficulties. Yet, despite these many challenges, NTSB staff produce thorough reports, presenting their considered opinions of what happened and why. In some cases, it is operator error, and in others a design flaw. In many cases, however, it is a combination of these factors that ultimately leads to disaster. We consider every cause of an accident, not for the purpose of laying blame, but with the intent of recommending interventions.

This investigation into the events of July 3, 2015, in Frisco, Colorado, demonstrates staff's determination to use all evidence, as well as what a lack of evidence reveals, to develop and support their probable cause theory. Many of their findings relate, ultimately, to the design integrity of the accident helicopter's safety systems. Design integrity is a concept involving disparate factors. Two of these factors, which must always be carefully balanced, are hardware design and the design of operating procedures. It is generally understood that it is impossible to design an entirely safe aircraft which would still be capable of flight. For this reason, engineers incorporate both hardware based safety features and safe operating procedures that should be used in concert in order to produce the intended functionality.

In this accident, the pilot, a well-regarded and experienced professional, apparently made two critical errors. First, he did not complete his pre-flight checklist. The missed steps were designed as part of operating procedures enabling a pilot to ascertain the proper functionality of the helicopter's hydraulic system. Second, he did not perform a crucial hover check, a safety measure intended to prevent a small error from turning into a catastrophic failure. As a pilot and flight instructor, I appreciate that even the best, most conscientious pilot can have a bad day. The NTSB statement of causal factors is not a general indictment of this pilot's proficiency nor does it negate his prior excellent record. However, we must impartially point out all causes relating to this accident in an effort to help future pilots avoid the same mistakes. This is why we, as an agency, repeatedly emphasize the importance of adherence to operating procedures and best practices, such as the use of preflight checklists and departure hover checks.

However, while an operator is the most important safety feature in any mode of transportation, no human being is perfect. Along with the employment of checklists and training to best practices, the NTSB also supports the use of effective technology that can assist operators in safely performing their duties. In this case, we have recommended a hardware design improvement, specifically, the incorporation of a visible and audible alert that could have given this pilot more time to recognize and correct his error. I wholly approve this recommendation. In addition, as new safety alerts and advisories are issued by manufacturers, it is vital that these manufacturers do all they can to both convey the true safety implications and to support corrective action through the swift provision of sufficient parts to meet demand by all those operating these aircraft.

One of the most disturbing aspects of this crash was the report from staff that despite his severe initial physical trauma, the pilot's injuries may have been survivable but for the almost immediate post-crash fire. I support staff's reiteration of the important recommendations regarding retrofitting existing helicopters. The NTSB has investigated too many helicopter crashes with post-crash fires. The events are all the more tragic when they result in serious or fatal injuries either to patients or the heroic pilots and medical teams responding to those in need. It is my hope that the recipients of the recommendations in this report and the larger flying community will consider carefully these events, incorporating lessons learned in an effort to improve air safety for all.

Acting Chairman Sumwalt and Members Hart and Dinh-Zarr joined in this statement.

4. Appendixes

Appendix A: Investigation

The National Transportation Safety Board (NTSB) was notified of this accident by the Summit County, Colorado, Sheriff's Office about 1500 mountain daylight time on July 3, 2015. An investigator from the NTSB's regional office in Denver, Colorado, arrived on scene the same day. An investigator from NTSB headquarters in Washington, DC, arrived on scene the next day. The following investigative groups were formed: airworthiness, meteorology, human performance, and survival factors. Also, specialists were assigned to perform video and performance studies, evaluate pilot medical issues, and examine the onboard image recorder.

Parties to the investigation were the Federal Aviation Administration (FAA), Air Methods Corporation, and the Professional Helicopter Pilots Association International. In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the NTSB's counterpart agency in France, the Bureau d'Enquêtes et d'Analyses pour la Sécurité de l'Aviation Civile (BEA) participated in the investigation as the representative of the State of Design and Manufacture (Airframe and Powerplants). Airbus Helicopters and Turbomeca participated in the investigation as technical advisors to the BEA, as provided in Annex 13.

Appendix B: Additional Information Regarding Safety Recommendations A-17-12 and -13

Previous Recommendations Related to Helicopter Operational Safety

The NTSB has issued numerous recommendations addressing multiple facets of helicopter operational safety, including Safety Recommendation A-06-15, which asked the FAA to require emergency medical service (EMS) operators to install terrain awareness and warning systems in all helicopters.[104] Also, in 2009, after the deadliest year for US helicopter emergency medical service (HEMS) operations (calendar year 2008, with 12 total accidents, 8 fatal accidents, and 29 fatalities), the NTSB held a public hearing to examine safety issues in the HEMS industry.[105] As a result of the information learned during the hearing, the NTSB issued multiple safety recommendations, including the following:

- A-09-90, which asked the FAA to require EMS operators to install flight data recording devices and establish a structured flight data monitoring (FDM) program;
- A-09-92, which asked the FAA to permit the HEMS aviation digital data service weather tool to be used by HEMS operators as an official weather product;
- A-09-95, which asked the FAA to require HEMS operators to install night vision imaging systems; and
- A-09-96, which asked the FAA to require that EMS helicopters be equipped with an autopilot and that it be used when a second pilot is not available.[106]

Safety Guidelines in Other Transportation Industries

Guidelines identifying recommended practices for improving safety have been successful in other transportation industries. For example, in 2005, the International Association of Oil and Gas Producers (IOGP) set a goal to reduce the risk of flying in an IOGP-contracted aircraft to the risk associated with flying in an average global airliner.[107] The IOGP then established recommended practices to be used in the development of contracting documents for fixed- and rotary-wing aircraft (IGOP 2008). These IOGP-recommended practices addressed, among other

[104] On September 11, 2014, the NTSB classified Safety Recommendation A-06-15 "Closed—Acceptable Action" as a result of a change to 14 *Code of Federal Regulations* Part 135 to require operators of helicopter air ambulances (HAA) to equip their helicopters with a terrain awareness and warning system.

[105] FAA Advisory Circular 135-14B, "Helicopter Air Ambulance Operations," dated March 26, 2015, stated that HEMS was an "obsolete term" and that the FAA and industry were moving to the term HAA "for enhanced accuracy." As a result, this report uses the term "HEMS" for previous NTSB actions only.

[106] On September 11, 2014, the NTSB classified Safety Recommendation A-09-90 "Open—Acceptable Response" pending information demonstrating that HAA operators are establishing the recommended FDM program. On April 1, 2015, the NTSB classified Safety Recommendation A-09-92 "Open—Acceptable Response" pending completion of the transition to an upgraded version of the HEMS weather tool on the aviation digital display platform. On September 11, 2014, the NTSB classified Safety Recommendations A-09-95 and -96 "Closed—Unacceptable Action" because neither the related notice of proposed rulemaking nor the related final rule included the revisions that the NTSB recommended.

[107] This goal mainly addressed flights to offshore oil platforms. Information about the International Association of Oil and Gas Producers is available on the association's website (http://www.iogp.org, accessed February 2, 2017).

things, enhancing airworthiness and safety by operating aircraft that met the most recent FAA and European Aviation Safety Agency design standards, including those involving crashworthiness. Preliminary results indicated that (1) IOGP members that followed the recommended practices had accident rates that were lower than IOGP members that did not follow those practices and (2) the accident rates of the IOGP members that followed the recommended practices were lower than those of the helicopter industry as a whole (Sheffield 2008).

Similarly, the National Collegiate Athletic Association and the American Council on Education worked with United Educators Insurance to develop and distribute recommended guidelines for the safe transportation of students in response to NTSB Safety Recommendation A-03-1.[108] The resulting report, titled *Safety in Student Transportation: A Resource Guide for Colleges and Universities*, was released in May 2006, and more than 6,000 copies of the report were distributed to college and university presidents, athletics directors, senior athletics administrators, business managers, and risk managers. The three organizations also urged colleges and universities to adopt the guidelines. As a result of the comprehensive nature of the guidelines and the effort to distribute and ensure adherence to the guidelines, the NTSB classified Safety Recommendation A-03-1 "Closed—Exceeds Recommended Action" on January 19, 2007.[109]

[108]The NTSB issued Safety Recommendation A-03-1 as a result of our investigation of the January 2001 fatal accident involving an airplane transporting Oklahoma State University basketball team members and associated team personnel near Strasburg, Colorado (NTSB 2003). Safety Recommendation A-03-1 asked the National Collegiate Athletic Association, the American Council on Education, and the National Association of Intercollegiate Athletics to "review Oklahoma State University's postaccident team travel policy and develop, either independently or jointly, a model policy for member institutions to use in creating a travel policy or strengthening an existing travel policy."

[109] The NTSB rarely assigns this classification, which recognizes the efforts of an organization to improve transportation safety in a manner above and beyond what the NTSB envisioned when the safety recommendation was issued. This classification applied to the actions that the National Collegiate Athletic Association and the American Council on Education took regarding the recommendation. The NTSB classified the National Association of Intercollegiate Athletics' actions regarding the recommendation "Closed—No Longer Applicable" on January 19, 2007.

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