Loss of Control While Maneuvering
Pilatus PC-12/45, N128CM
Butte, Montana
March 22, 2009

Accident Report

NTSB/AAR-11/05
PB2011-910405

National
Transportation
Safety Board

ERRATA

THE CORRECTIONS BELOW ARE *INCLUDED*
IN THIS REVISED VERSION OF THE DOCUMENT

AIRCRAFT ACCIDENT REPORT
NTSB/AAR-11/05

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June 5, 2012

- Page 80 has been updated to include the NTSB Board Member signature block and the adoption date of the report.

NTSB/AAR-11/05
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Aircraft Accident Report

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National
Transportation
Safety Board

490 L'Enfant Plaza, S.W.
Washington, D.C. 20594

National Transportation Safety Board. 2011. ***Loss of Control While Maneuvering, Pilatus PC-12/45, N128CM, Butte, Montana, March 22, 2009*****. NTSB/AAR-11/05. Washington, DC.**

Abstract: This accident report discusses the March 22, 2009, accident in which a Pilatus PC-12/45, N128CM, was diverting to Bert Mooney Airport (BTM), Butte, Montana, when it crashed about 2,100 feet west of runway 33 at BTM. The safety issues discussed in the report address fuel system limitations, requirements for fuel filler placards, and guidance on fuel system icing prevention. Safety recommendations concerning these issues are addressed to the Federal Aviation Administration (FAA) and the European Aviation Safety Agency. Previous safety recommendations concerning crash protection for airplane occupants and flight recorder systems were addressed to the FAA.

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Abbreviations and Acronyms

AC	advisory circular
AFM	airplane flight manual
agl	above ground level
ANL	airplane nose left
ARTCC	air route traffic control center
ASOS	automated surface observing system
ASRS	aviation safety reporting system
ATC	air traffic control
ATD	anthropomorphic test dummy
ATIS	automatic terminal information service
AWOS	automated weather observing system
BOI	Boise Air Terminal/Gowen Field
BTM	Bert Mooney Airport
BZN	Gallatin Field
CAA	Civil Aviation Authority
CAWS	central advisory and warning system
CFR	*Code of Federal Regulations*
CVR	cockpit voice recorder
DLN	Dillon Airport
EASA	European Aviation Safety Agency
EIS	engine instrument system
ERAM	en route automation modernization

EUROCAE	European Organization for Civil Aviation Equipment
FAA	Federal Aviation Administration
FBO	fixed-base operator
FDR	flight data recorder
FL	flight level
FSII	fuel system icing inhibitor
Hg	mercury
IFR	instrument flight rules
LLJ	Challis Airport
NASA	National Aeronautics and Space Administration
NOTAM	notice to airmen
NTSB	National Transportation Safety Board
OVE	Oroville Municipal Airport
PDT	Pacific daylight time
psi	pounds per square inch
REI	Redlands Municipal Airport
RWD	right wing down
SB	service bulletin
TSB	Transportation Safety Board of Canada
TSO	technical standard order
TWF	Joslin Field/Magic Valley Regional Airport
VCB	Nut Tree Airport
VFR	visual flight rules
VMC	visual meteorological conditions

Executive Summary

On March 22, 2009, about 1432 mountain daylight time, a Pilatus PC-12/45, N128CM, was diverting to Bert Mooney Airport (BTM), Butte, Montana, when it crashed about 2,100 feet west of runway 33 at BTM. The pilot and the 13 airplane passengers were fatally injured, and the airplane was substantially damaged by impact forces and a postcrash fire. The airplane was owned by Eagle Cap Leasing of Enterprise, Oregon, and was operating as a personal flight under the provisions of 14 *Code of Federal Regulations* Part 91. The flight departed Oroville Municipal Airport, Oroville, California, on an instrument flight rules flight plan with a destination of Gallatin Field, Bozeman, Montana. Visual meteorological conditions prevailed at the time of the accident.

The National Transportation Safety Board determines that the probable cause of this accident was (1) the pilot's failure to ensure that a fuel system icing inhibitor was added to the fuel before the flights on the day of the accident; (2) his failure to take appropriate remedial actions after a low fuel pressure state (resulting from icing within the fuel system) and a lateral fuel imbalance developed, including diverting to a suitable airport before the fuel imbalance became extreme; and (3) a loss of control while the pilot was maneuvering the left-wing-heavy airplane near the approach end of the runway.

The safety issues discussed in this report address fuel system limitations, requirements for fuel filler placards, and guidance on fuel system icing prevention. Safety recommendations concerning these issues are addressed to the Federal Aviation Administration (FAA) and the European Aviation Safety Agency. Previous safety recommendations concerning crash protection for airplane occupants and flight recorder systems were addressed to the FAA.

NOTE: This report was reissued on April 17, 2023, with corrections on pages 49, 56, 66-68, 76, and 77 and the addition of Board Member Concurrences on page 81 that were not included in the previous posted report.

1. Factual Information

1.1 History of Flight

On March 22, 2009, about 1432 mountain daylight time,[1] a Pilatus PC-12/45, N128CM, was diverting to Bert Mooney Airport (BTM), Butte, Montana, when it crashed about 2,100 feet west of runway 33 at BTM. The pilot and the 13 airplane passengers were fatally injured, and the airplane was substantially damaged by impact forces and a postcrash fire. The airplane was owned by Eagle Cap Leasing of Enterprise, Oregon, and was operating as a personal flight under the provisions of 14 *Code of Federal Regulations* (CFR) Part 91. The flight departed Oroville Municipal Airport (OVE), Oroville, California, on an instrument flight rules (IFR) flight plan with a destination of Gallatin Field (BZN), Bozeman, Montana. Visual meteorological conditions (VMC) prevailed at the time of the accident.

On March 21, 2009 (the day before the accident), the pilot had the airplane fueled with 222 gallons of Jet A fuel at Redlands Municipal Airport (REI), Redlands, California, where the airplane was based.[2] During a postaccident interview, the fueling station manager stated that the pilot did not request that a fuel system icing inhibitor (FSII) be added.[3] (All jet fuels contain trace amounts of water, and a FSII lowers the freezing point of water to -40º C to prevent the water from turning into ice crystals, which can block a fuel line or filter.)[4] The Pilatus PC-12 Airplane Flight Manual (AFM), section 2, Limitations, dated March 30, 2001, stated that an "anti-icing additive [FSII] must be used for all flight operations in ambient [outside air] temperatures below 0º C." On a standard day, the temperature is 0° C at 7,500 feet, so most PC-12 flights would require the use of a FSII.[5]

About 1946 Pacific daylight time (PDT) on the day before the accident, the pilot filed three flight plans for the next day with an automated flight service station. The pilot listed BZN as the destination airport for the final flight leg and BTM as the alternate airport for that flight leg.

On March 22, 2009, the pilot departed REI for Nut Tree Airport (VCB), Vacaville, California, about 0742 PDT and arrived at VCB about 0930 PDT. Data downloaded from the airplane's central advisory and warning system (CAWS) showed that, for the flight from REI to VCB, the left and right fuel boost pumps began cycling (that is, turning on for about 10 seconds

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[1] All times in this report are mountain daylight time unless indicated otherwise.

[2] The fueling station manager and a fueler at REI both indicated that the airplane's fuel tanks had been filled to capacity.

[3] The fuel truck at REI contained fuel that was not premixed with a FSII, but the fuel pump contained provisions for injecting a FSII during fueling. Fuel records showed that, between February 27 and March 21, 2009, the airplane had been fueled at REI four times and that a FSII was not added to the fuel each of those times.

[4] All temperatures in this report appear in Celsius, even though some source documents cited in the report expressed temperatures in Fahrenheit; 32º F equals 0º C.

[5] According to the Federal Aviation Administration's (FAA) Instrument Flying Handbook, in the standard atmosphere, sea level pressure is 29.92 inches of mercury (Hg), and the temperature is 15° C. The standard lapse rate for temperature is a 2° C decrease per 1,000-foot increase.

and then off for about 1 second) about 1 hour 30 minutes into the flight.[6] About 15 minutes later, the left fuel boost pump was on continuously, and the right fuel boost pump was off. The left fuel boost pump remained on continuously for the rest of the flight.[7]

Fuel records indicated that the airplane had been refueled with about 128 gallons of Jet A fuel after the airplane's arrival at VCB. During a postaccident interview, the VCB airport manager stated that he saw the airplane at the airport's self-service fueling island but did not observe the airplane being refueled. The fuel dispensed at the VCB self-service fueling island was not premixed with a FSII,[8] and the fuel pump did not contain provisions for injecting a FSII during fueling. VCB personnel found no evidence to suggest that the pilot had used any other method to add a FSII to the fuel either before or during the fueling.[9]

The airplane departed VCB about 1020 PDT with nine passengers (four adults and five children) and the pilot on board, although the flight plan indicated that four passengers and the pilot would be on board during that flight leg. The airplane arrived at OVE about 1033 PDT. CAWS data showed no fuel boost pump activity during the 13-minute flight.

At OVE, four passengers (two adults and two children) boarded the airplane, resulting in a total of 13 passengers (six adults and seven children, who ranged in age from 1 to 9 years).[10] The flight plan indicated that eight passengers and the pilot would be on board the airplane during the final flight leg. The accident airplane was configured with two pilot seats and eight passenger seats. Because each flight on the day of the accident was a single-pilot operation, one seat in the cockpit could be used by a passenger.

The airplane departed OVE for BZN about 1210 (1110 PDT). The IFR flight plan indicated that the airplane would have 3 hours 30 minutes of fuel on board with an estimated en route time of 2 hours 30 minutes. The airplane's radar ground track as the flight progressed and the planned flight route are shown in figure 1. About 1228, a controller at the Oakland Air Route Traffic Control Center (ARTCC) cleared the airplane direct to BZN; about 1244, the pilot made initial contact with a controller at the Salt Lake ARTCC.

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[6] Fuel boost pumps provide fuel system pressure when a low fuel pressure state exists and balance the fuel load between the left and the right wing fuel tanks. Information about the PC-12 fuel system, including the fuel boost pumps, is discussed in section 1.6.1. The CAWS is discussed further in sections 1.6.2 and 1.16.2.

[7] The CAWS logged events either as "activated" (on) or "cleared" (off).

[8] Fuel samples from the VCB self-service fueling island were secured in a sealed container on the day after the accident. The samples were sent to the Air Force Petroleum Agency at Wright-Patterson Air Force Base, Ohio, for testing and analysis. The agency found no FSII present in the samples.

[9] The National Transportation Safety Board (NTSB) obtained surveillance video from VCB that showed the accident airplane's arrival at the self-service fueling island. The airplane was visible on the video for about 36 minutes. During that time, the pilot exited the airplane and serviced it with fuel, the pilot and passengers boarded the airplane, and the airplane departed. The video showed no evidence that the pilot had sampled fuel from either of the underwing fuel tank drains or the fuel filter drain. (Sampling fuel would have provided the pilot with an opportunity to determine if the fuel contained any contaminants, including water.)

[10] After the accident, one of the owners of the airplane (who organized the flights) stated that the airplane had carried the same number of adult and child passengers on previous flights. This owner did not consider weight and balance to be an issue because the airplane had previously transported 10 adults on the same flight, but he acknowledged that, for this flight, "there were just not enough seatbelts." The owner further stated that the adults "could hold children on laps and put them on the floor to sleep."

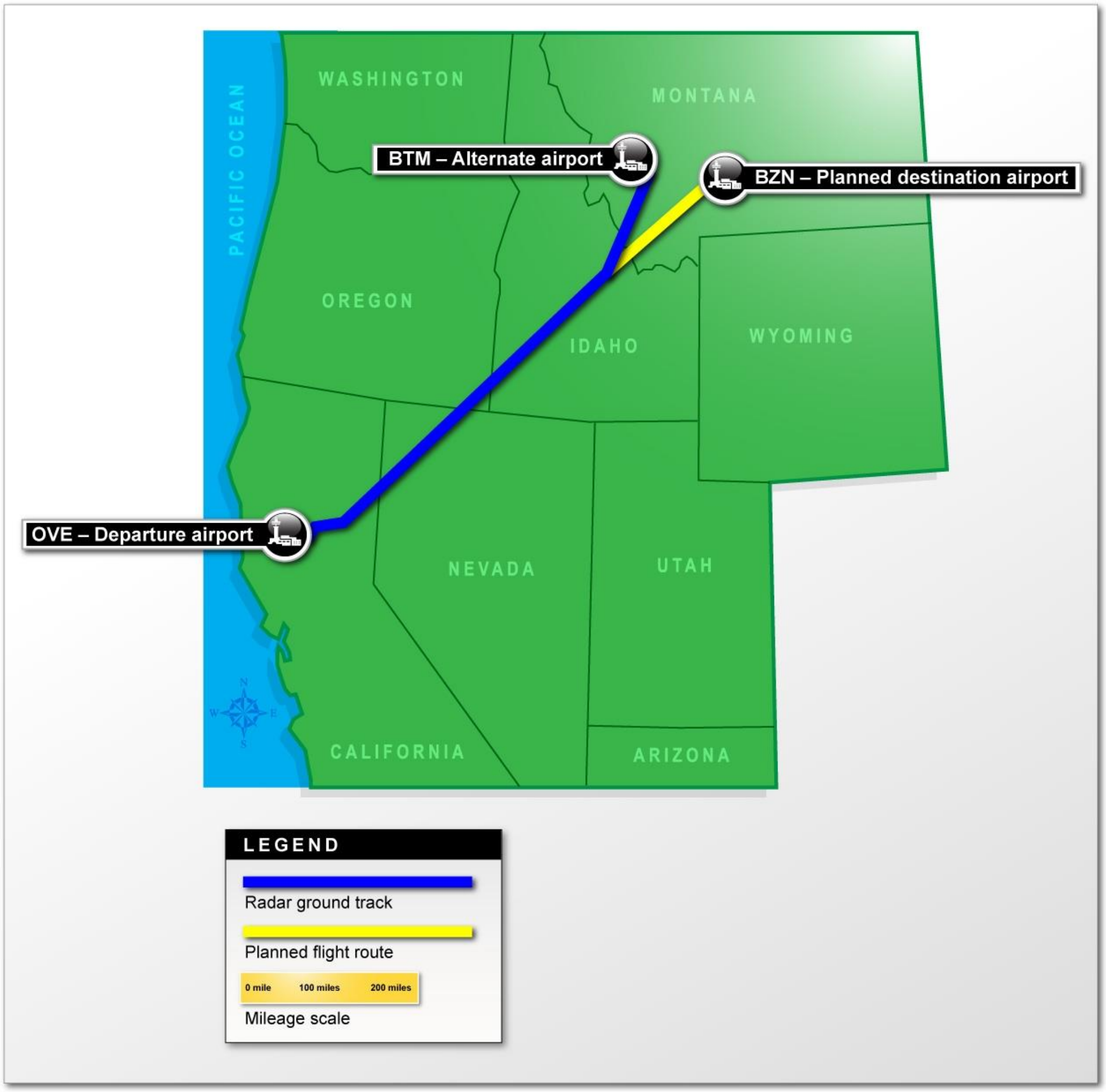

Figure 1. Radar ground track and planned flight route.

At 1308:53, while the airplane was under control of the Salt Lake ARTCC, the pilot asked to leave the ARTCC frequency for 2 to 3 minutes. After the ARTCC sector 31 controller approved the pilot's request (and instructed him to report when he was back on the ARTCC frequency), the pilot contacted Salt Lake Flight Watch to request weather information for BZN and provide a pilot report of the weather. (The pilot did not request weather information for BTM.) The pilot returned to the Salt Lake ARTCC frequency at 1312:51.

CAWS data revealed that the left and right fuel boost pumps began cycling about 1323 (1 hour 13 minutes into the flight). For about 3 minutes starting about 1328, the left fuel boost pump was on continuously, and the right fuel boost pump was off. After that time, the right fuel boost pump was cycling or was on continuously, and the left fuel boost pump was on continuously or was off.

At 1359:28, the pilot contacted the Salt Lake ARTCC sector 6 radar controller. At that time, the airplane was operating at flight level (FL) 250,[11] as assigned by air traffic control (ATC). Radar data showed that, at 1402:52, the pilot changed the airplane's route of flight and turned to the left toward BTM without ATC clearance.[12] At 1403:25, the pilot contacted the controller to request a change in destination to BTM but did not provide a reason for the requested divert. The controller did not question the pilot's request. The controller then cleared the airplane direct to BTM and instructed the pilot to maintain FL250. The pilot acknowledged the clearance at 1403:35.

Radar data showed that the airplane began a descent from FL250 at 1404:09. About 25 seconds later, the pilot contacted the controller to request a lower altitude. The controller issued the altimeter setting for BTM and cleared the airplane to descend at the pilot's discretion to an altitude of 14,000 feet mean sea level (which was just above the 13,100-foot minimum IFR altitude for the area).[13] The pilot acknowledged the clearance.

At 1405:23, the pilot transmitted a second request to change the flight's destination to BTM. The controller told the pilot that he had previously cleared the airplane to BTM, and the pilot responded by stating that the airplane was descending to 14,000 feet. At 1406:15, the controller instructed the pilot to "advise receipt of Butte Montana weather and notams [notices to airmen]."[14] The pilot responded, "wilco," indicating that he would comply with the instruction. The ATC transcript showed that the pilot did not report receipt of BTM weather and NOTAM information and that the controller did not follow up with the pilot to ensure that he had received this information. About 1419, the controller was relieved from his position as part of a normal rotation schedule, but he did not tell the relief controller that the pilot had not reported receipt of weather and NOTAM information for BTM.

At 1422:50, the next sector 6 controller to handle the accident airplane cleared the airplane to descend and maintain 13,000 feet and advised the pilot of the airplane's position relative to BTM. The controller also instructed the pilot to report when he had the airport in sight for a visual approach. The pilot acknowledged the controller's instruction. At 1424:38, the pilot requested a lower altitude, and the controller cleared the airplane to descend and maintain 12,200 feet, which was the minimum IFR altitude at that point in the approach. The pilot acknowledged this clearance.

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[11] According to the pilot glossary in the FAA's *Aeronautical Information Manual*, flight level is a constant atmospheric pressure related to a reference datum of 29.92 inches of Hg. FL250 represents a barometric altimeter indication of 25,000 feet.

[12] Title 14 CFR 91.123, "Compliance With ATC Clearances and Instructions," states, "when an ATC clearance has been obtained, no pilot in command may deviate from that clearance unless an amended clearance is obtained, an emergency exists, or the deviation is in response to a traffic alert and collision avoidance system resolution advisory." The regulation also states, "each pilot in command who, in an emergency, or in response to a traffic alert and collision avoidance system resolution advisory, deviates from an ATC clearance or instruction shall notify ATC of that deviation as soon as possible."

[13] In this report, all altitudes 18,000 feet and below are expressed as mean sea level unless indicated otherwise. (The 18,000-foot altitude is known as the "transition altitude" in the United States and Canada. The transition altitude is a published height above sea level at which pilots, while climbing to their cruising level, change the airplane's barometric altimeter from the regional pressure setting to the standard pressure setting of 29.92 inches of Hg.)

[14] The pilot could have received BTM weather information from a flight service station or the BTM automated surface observing system. The pilot could have received NOTAM information for BTM from a flight service station.

Radar data showed that the airplane descended below 12,200 feet at 1426:49 and continued descending. (The pilot was required to comply with the previous ATC-issued altitude restriction until he had the airport in sight and could provide his own terrain clearance.) CAWS data showed that, about 1427 (2 hours 17 minutes into the flight), the system provided a caution to the pilot indicating that a low fuel condition existed in the right fuel tank.

At 1427:27, the controller advised the pilot that BTM was at his 12:00 position 12 miles away and asked the pilot whether the airport was in sight.[15] The pilot responded, "yeah as soon as we get past one more cloud." At 1428:43, the pilot reported that he had the airport in sight and canceled his IFR clearance. Radar data about that time showed that the airplane was 8 miles southwest of BTM at an altitude of 11,100 feet. At 1428:49, the controller acknowledged the pilot's IFR clearance cancellation, instructed him to squawk visual flight rules (VFR) transponder code 1200, and advised him that no known or observed traffic existed between the airplane and the airport. The pilot did not acknowledge this transmission, and no further communications occurred between the pilot and ATC.[16]

Radar data showed that the airplane continued to squawk the previously assigned discrete transponder code as the airplane continued toward the airport. BTM has no ATC tower, but an employee at a BTM fixed-base operator (FBO), who was monitoring the common traffic advisory frequency when the accident airplane was approaching the airport, heard the pilot indicate that the airplane would be landing on runway 33. The last recorded radar target, at 1430:25, showed that the airplane was at an altitude of 9,100 feet (3,550 feet above ground level [agl]) and about 1.8 miles southwest of the runway 33 threshold.[17] The final radar targets are shown in figure 2 along with a depiction of the terrain surrounding BTM (which is further described in section 1.10).

[15] All distances in this report are expressed as nautical miles unless indicated otherwise.

[16] The ATC transcript showed that the controller tried to contact the pilot at 1429:32.

[17] The airplane's calculated groundspeed between the final two radar targets (1430:13 and 1430:25) was about 189 knots.

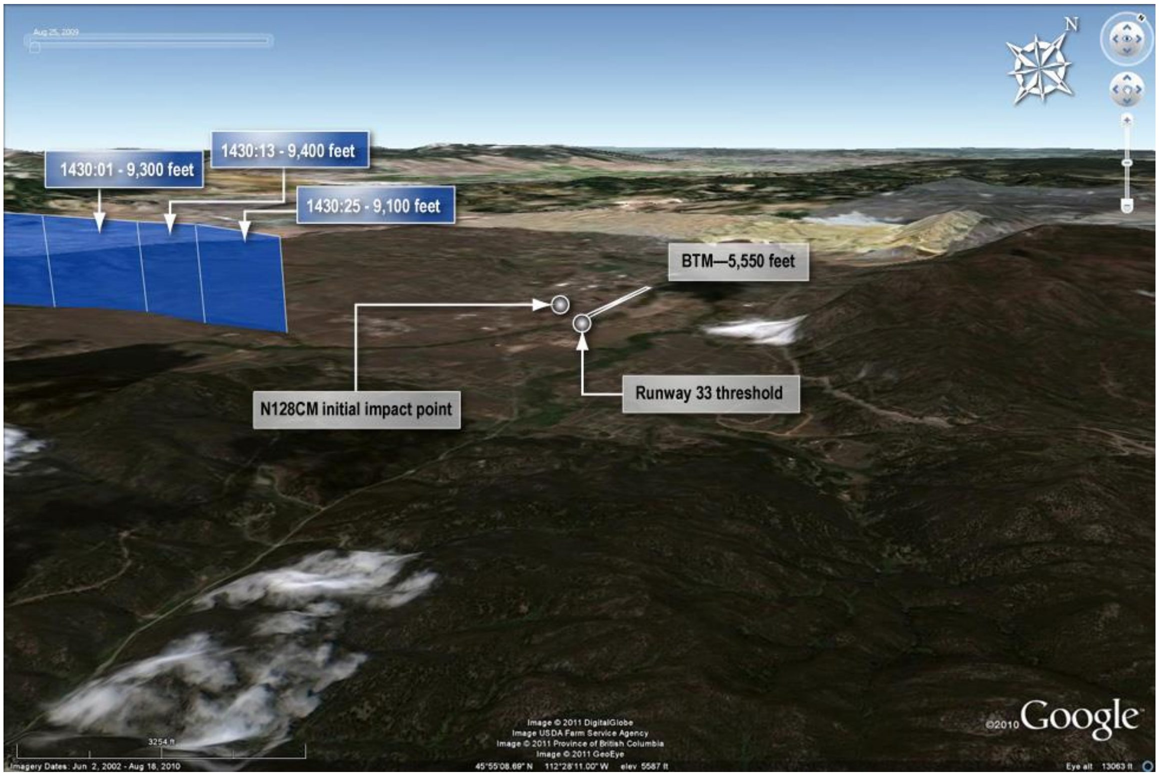

Figure 2. Final radar targets and terrain surrounding Butte, Montana (looking northwest).

The airplane impacted the ground about 2,100 feet west of the runway 33 centerline. The first emergency call reporting the accident to police was received at 1432:26. Witnesses to the accident reported that the airplane was approaching runway 33 at a higher altitude than other airplanes that land at the airport. The witnesses also reported that the airplane had entered a steep left turn at an estimated altitude of 300 feet agl and that the nose of the airplane then pitched down suddenly. No witnesses reported any indications of smoke or an in-flight breakup.[18] CAWS data, along with radar data and assumptions about fuel burn (described in section 1.16.3) indicated a left-wing-heavy fuel condition before the accident occurred.

[18] Some of the witnesses were driving along a main street in Butte that runs north to south and is west of the airport. Another witness was driving north-northeast of the accident site. Several other witnesses were outside when the accident occurred. These witnesses were located near residences on the east side of the approach end of runway 33 and to the west of the accident site or were visiting the cemetery where the accident airplane came to rest.

1.2 Injuries to Persons

Table 1. Injury chart.

Injuries	Flight crew	Cabin crew	Passengers	Other	Total
Fatal	1	0	13	0	14
Serious	0	0	0	0	0
Minor	0	0	0	0	0
None	0	0	0	0	0
Total	1	0	13	0	14

1.3 Damage to Aircraft

The airplane was substantially damaged by impact forces and postcrash fire.

1.4 Other Damage

The airplane impacted a cemetery west of BTM runway 33 and damaged numerous markers within the cemetery.

1.5 Personnel Information

The pilot, age 65, held a Federal Aviation Administration (FAA) airline transport pilot certificate with a rating for multiengine land and commercial privileges for airplane single-engine land. The pilot's most recent second-class medical certificate was dated April 4, 2008, with the limitation that the holder must possess corrective glasses for near vision.[19]

According to his applications for an airman medical certificate and Eagle Cap Leasing company records, the pilot had flown for the U.S. Air Force between 1969 and 1972 and was type rated on the Lockheed L-300 and T-33. The pilot had also flown the DC-8 for Trans International Airlines (1972 to 1973), Southern Airways (1973 to 1974, equipment unknown), and Resort Commuter Airlines (1988 to 1989, equipment unknown). In addition, he flew the PC-12 for Native American Air Ambulance (1999 to 2002). (When he was not employed as a professional pilot, the pilot worked in various fields that were not related to aviation.)

The pilot was hired by Eagle Cap Leasing in November 2002 as a contract pilot. Company records indicated that, at the time of the accident, the pilot had accumulated 8,840 hours total flight time, with 1,760 hours in the PC-12, and he had flown 35, 26, and 10 hours in the 90, 60, and 30 days preceding the accident. Company records also indicated that

[19] The NTSB was not able to determine whether the pilot was wearing his glasses during the accident flight. Also, a review of the pilot's airman medical records showed that he had been evaluated for a heart murmur in 1960 and that no evidence of a heart abnormality was detected. The records further showed that the pilot had no symptoms of heart disease.

the pilot flew the accident airplane from OVE to BZN on March 7, 2008. FAA records indicated no previous accidents, incidents, or enforcement actions.

The pilot's most recent recurrent PC-12 training was completed on January 9, 2009. The instructor (from Aviation Training Management of Vero Beach, Florida) stated that he had conducted several previous training sessions with the pilot between 2003 and 2009. The instructor reported that, during the latest session, he and the pilot discussed slow flight, stall, and icing procedures and reviewed emergency procedures for the airplane.[20] The instructor also reported that the pilot showed a "very high level" of competency in the airplane and "superb" professional judgment. Further, the instructor stated that, during a postflight briefing, the pilot indicated that he had not experienced any undue pressure to fly in bad weather or with mechanical problems.

On March 18, 2009, the pilot flew passengers aboard the accident airplane on a trip that departed REI about 1130 PDT and arrived at Cabo San Lucas, Mexico, about 3 hours later. The pilot then stayed at a local hotel until the morning of March 21. His specific activities during that time are unknown.[21] The pilot and passengers departed Cabo San Lucas on March 21 about 1030 PDT and arrived at REI about 1530 PDT after stopping in San Diego, California, to clear U.S. Customs. After arriving at REI, the pilot prepared the airplane for the trip to BZN, acknowledged a change to the trip,[22] and filed three flight plans. No further information was available regarding the pilot's activities until he departed REI for VCB the next day (March 22).

The accident airplane had three owners. One owner, who organized the flights occurring on the day of the accident, stated that he helped hire the pilot. This owner indicated that he had flown with the pilot for more than 5 years and that he had sat in the right cockpit seat about one-fifth of the time that he flew with the pilot. This owner also indicated that the pilot was professional and that the only issue involving the pilot entailed a "hot start" (that is, when the temperature exiting the turbine section of an engine exceeds the expected exhaust gas temperature for the engine during start). Another owner of the airplane stated that the pilot was "straightforward and all business" and did not fly aggressively. This owner reported that the pilot flew frequently using flight instruments. The third owner of the airplane stated that, whenever he flew with the pilot, "there were never more passengers on the airplane than there were seats." This owner also reported that he saw the pilot use checklists during each flight.

The former director of operations for Native American Air Ambulance stated that the pilot was conscientious, competent, and professional. He recalled that a FSII was not added to fuel for the company's flights because they were short trips that were not conducted at high

[20] The instructor stated that the use of a FSII was not specifically discussed during this training session but had been discussed during previous sessions. The instructor also stated that the pilot was "well aware" of the need to use this additive.

[21] The pilot's wife declined to be interviewed by the NTSB as part of its investigation of this accident.

[22] The airplane owner who organized the trip stated that the original plan was for the pilot to make two flights to BZN, first picking up passengers at Lodi and Napa County Airports (in Acampo and Napa, California, respectively) and transporting them to BZN and then traveling to OVE to pick up additional passengers and transport them to BZN. However, on March 21, the owner decided to drive to Bozeman so that two trips to BZN would not be necessary. Also, some of the passengers agreed to meet the airplane at VCB instead of Lodi and Napa County Airports to simplify the trip plan. According to the owner, the pilot confirmed the new flight plan during the day on March 21.

altitudes. The previous chief pilot for the company stated that the accident pilot was “extremely knowledgeable” about the PC-12 and that he had “nothing but praise” for the pilot’s flying ability and overall professionalism.

1.6 Aircraft Information

The Pilatus PC-12/45 is a low-wing, T-tail, single-engine airplane designed to transport passengers, cargo, or both. In June 1996, the Federal Office for Civil Aviation of Switzerland issued the original type certificate for the PC-12/45,[23] and the FAA validated the certification in July 1996. The FAA’s type certificate data sheet for the PC-12 showed that the airplane’s certification basis included the requirements of 14 CFR Part 23, “Airworthiness Standards: Normal, Utility, Acrobatic, and Commuter Category Airplanes.” The version of the Pilatus PC-12 Pilot’s Operating Handbook and AFM that was in effect at the time of the accident was approved by the Federal Office for Civil Aviation of Switzerland in September 2007.

The accident airplane (serial number 403) was manufactured in 2001. The airplane was equipped with a Pratt & Whitney PT6A-67B turbine engine and a four-bladed, constant-speed propeller manufactured by Hartzell Propeller. Eagle Cap Leasing purchased the airplane in August 2002.

A logbook entry (from the engine trend monitoring page) on the day of the accident indicated that the airplane had accumulated 1,916 total flight hours. The most recent annual inspection of the airplane, engine, and propeller was completed on October 9, 2008. At that time, the airplane had accumulated 1,815 total flight hours, the engine had accumulated 1,359 total flight cycles, and the engine and the propeller had accumulated 1,815 hours time since new. The airplane was in compliance with all applicable airworthiness directives.

The airplane was configured with two pilot seats and eight passenger seats. Two of the passenger seats faced aft, and the other six passenger seats faced forward. The Pilatus PC-12 AFM, section 2, Limitations, dated November 24, 1995, stated that, for a corporate commuter configuration, “a maximum of 9 seats may be installed in the cabin in addition to the 2 crew seats.” The AFM also stated that, for a corporate commuter configuration, the “maximum number of occupants is 9 passengers plus pilot(s).”[24]

The maximum takeoff weight and landing weight for the airplane was 9,921 pounds. The National Transportation Safety Board (NTSB) found no evidence indicating that the pilot had completed weight and balance computations for any of the flights on the day of the accident.[25] The estimated weight and balance computations for each flight segment are shown in table 2.

[23] On June 23, 2006, the European Aviation Safety Agency began oversight of the PC-12/45 certificate on behalf of Switzerland.

[24] The limitation on the maximum number of passenger seats was in accordance with 14 CFR 23.1583, “Operating Limitations,” paragraph (j), “Maximum Passenger Seating Configuration.” The limitation on the number of occupants that could be transported by the PC-12 was an operating limitation not required by section 23.1583.

[25] The Pilatus PC-12 AFM, section 6, Weight and Balance, dated March 30, 2001, stated that the pilot-in-command was responsible for ensuring that the aircraft would not exceed the maximum weight limits and was loaded within the center-of-gravity range before takeoff. According to FAA operations inspectors, this

Table 2. Estimated weight and balance computations.

Flight segment	Gross weight condition	Center-of-gravity condition
REI to VCB	Under takeoff weight by 725 pounds	Within limits
VCB to OVE	Over takeoff weight by 432 pounds	Within limits
OVE to BZN	Over takeoff weight by 572 pounds	Within limits
Divert to BTM	Under landing weight by 384 pounds	Within limits

The flight control system used push-pull rods and cables. Electric trim systems were provided for the aileron, rudder, and horizontal stabilizer, each of which was electrically operated from the cockpit. Deice boots were installed on the leading edges of the airplane's wings and horizontal stabilizer. When activated by the pilot, the boots inflated and dispersed ice that had accumulated on those surfaces during flight in atmospheric icing conditions.[26]

1.6.1 Fuel System

Fuel for the PC-12 is contained in left and right wing integral tanks. Each wing tank contains a main tank and a collector tank.[27] Fuel drains located under the collector tanks and at the fuel filter (discussed later in this section) are used to remove water and other contaminants during preflight inspections. A fuel vent bay incorporates inward and outward vents that allow air to take the place of fuel as the fuel exits the system.

Refueling is accomplished using overwing outboard filler ports, and each wing tank has a usable capacity of 201 gallons.[28] A placard specifying the total fuel capacity and usable capacity for each fuel tank and the type of fuel to be used (Jet A, Jet A-1, or Jet B) is located near each fuel filler port.[29] The PC-12 AFM, section 8, "Handling, Servicing, and Maintenance," dated March 30, 2001, stated the following information under a "CAUTION" box:

> As the anti-icing additive is not always indicated on the fueling installation placard [on a fuel truck or fuel pump], check with the fuel supplier to make sure the fuel contains an approved anti-icing additive.

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provision implied that a pilot could use methods other than a weight and balance form, including a calculator or mental math, to fulfill the requirement.

[26] The deice system was controlled by a switch in the cockpit, and a deice boot timer activated each deice boot (two on each wing and one on the horizontal stabilizer) for 8 seconds. The total time to inflate and deflate all five deice boots was 40 seconds, which was followed by a period of either 20 or 140 seconds (depending on the cycle setting) before the inflation and deflation sequence could restart.

[27] A check valve installed within a motive flow fuel supply line in each collector tank prevents fuel from flowing between the left and the right wing tanks.

[28] The Pilatus PC-12 AFM, section 2, Limitations, dated March 30, 2001, stated that the airplane had a 406.8-gallon (2,736-pound) total fuel capacity, with 402 gallons (2,704 pounds) of usable fuel and 4.8 gallons (32 pounds) of unusable fuel. The unusable fuel could not be used for flight planning purposes because it was considered unavailable. Each tank had a total fuel capacity of 1,368 pounds and a usable fuel capacity of 1,352 pounds.

[29] Title 14 CFR 23.1557, "Miscellaneous Markings and Placards," stated that fuel filler openings for turbine-powered airplanes must be marked at or near the filler cover with the words "Jet Fuel" and either the permissible fuel designations or references to the AFM for the permissible fuel designations.

If it is known that the aircraft will fly in ambient temperatures of less than 0º C and if the fuel does not contain an anti-icing additive, one must be blended with the fuel during fueling.

Fuel is transferred from the wings to the engine by a motive flow jet pump system (that is, a system that draws fuel into a pump with a suction force that is created by lowering the pressure of an induced flow of fuel to the pump), as described below and shown in figure 3. The fuel supplied to the engine exceeds the amount required for all ground and flight operations. The fuel supply that is greater than the engine demand is returned to the fuel tanks via a fuel control return line.

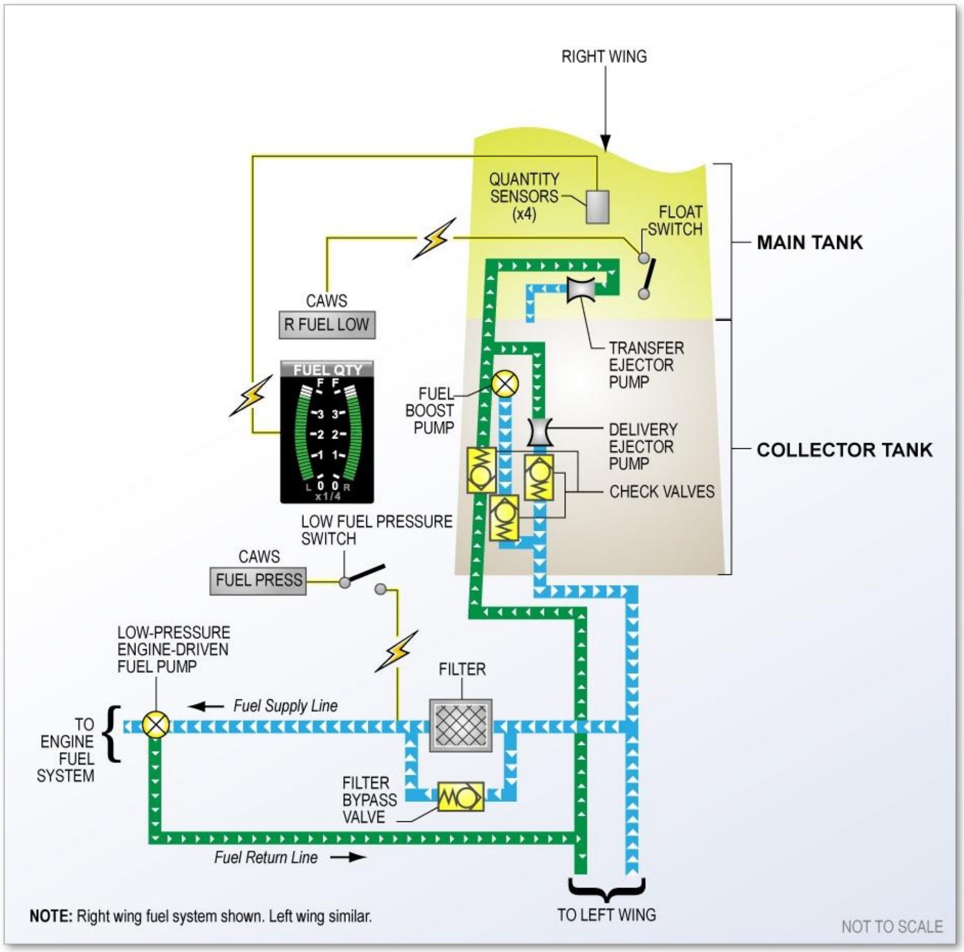

Figure 3. PC-12 fuel system.

Note: Fuel supply lines are shown in blue; fuel return lines are shown in green. Some fuel system components discussed in this section are not shown in the figure. These components are the maintenance shutoff valve, air separator, fuel drains, firewall shutoff valve, and fuel control return line.

A transfer ejector pump in each main tank transfers fuel from the aft portion of the main tank to its respective collector tank. A delivery ejector pump in each collector tank transfers fuel to a common manifold. Both the transfer ejector pumps and the delivery ejector pumps are powered by a motive flow of fuel from a low-pressure engine-driven fuel pump. An electrically-driven fuel boost pump in each collector tank transfers fuel if (1) either of the delivery ejector pumps is unable to supply the required pressure to move the fuel toward the engine or (2) the low-pressure engine-driven fuel pump fails.[30] The fuel boost pumps serve two other purposes: they provide fuel pressure during engine start and balance the fuel load between the left and the right tanks. (Fuel balancing is discussed later in this section.)

The fuel boost pumps are centrifugal-style pumps that incorporate an electric motor-driven impeller. Each pump is controlled by a two-position (AUTO or ON) switch located on the fuel pump section of the overhead panel in the cockpit. With the switches set to the AUTO position (the normal operating setting), the boost pumps operate automatically whenever fuel system pressure falls below 2 pounds per square inch (psi). The boost pumps turn off automatically 10 seconds after the fuel system pressure is restored to 3.5 psi. When the switches are set to the ON position, the boost pumps operate continuously. Fuel boost pump operation and low fuel pressure conditions are indicated on the CAWS, which is discussed in section 1.6.2.

From the wing tanks, fuel flows through a maintenance shutoff valve and a fuel filter. The fuel filter incorporates a spring-loaded bypass valve that would open and allow fuel to bypass the filter if it were to become blocked. The bypass valve was calibrated to operate at a differential pressure of 8 psi ± 1 psi. If a bypass condition were to occur, then a differential pressure indicator would extend a red button, which would not be visible to the pilot during flight but could be observed by the pilot during the next preflight inspection.[31]

Fuel is then directed from the fuel filter to an air separator. The air separator passes air in the fuel system to the fuel control return line and incorporates a switch that detects low fuel pressure. The fuel then passes through a firewall shutoff valve to the low-pressure engine-driven fuel pump, which includes a pressure relief valve that maintains a fuel pump output pressure of 43.5 psi. If the low-pressure engine-driven pump were to fail, a bypass valve would allow fuel to flow around the pump.

Fuel is delivered from the low-pressure engine-driven pump to the engine fuel system, which includes a fuel-oil heat exchanger, a high-pressure engine-driven pump, and a fuel control unit. The fuel-oil heat exchanger, which is located downstream from the fuel filter, preheats the fuel to prevent ice from forming as the fuel moves toward the engine. After the fuel passes through the fuel-oil heat exchanger, the high-pressure engine-driven fuel pump delivers the fuel to the fuel control unit, which directs the fuel to the engine fuel nozzles.

Fuel quantity is measured by four fuel probes in each fuel tank, and indications of fuel quantity are displayed on the engine instrument system (EIS).[32] One of the two fuel quantity indicators on the EIS contains 28 liquid crystal display segments—each of which is referred to as

[30] The delivery ejector pumps have a nominal output pressure of 5 pounds per square inch (psi), and the fuel boost pumps have a nominal output pressure of 31 psi.

[31] The Pilatus PC-12 AFM, section 4, Normal Procedures, dated September 1, 2000, stated that the pilot was to ensure that the indicator was flush with the fuel filter housing assembly during preflight inspections. The surveillance video from VCB did not show any evidence that the pilot performed this part of the preflight inspection.

[32] In addition to fuel boost pump operation and low fuel pressure conditions, the CAWS can also annunciate a low fuel condition in one or both fuel tanks. The CAWS senses fuel quantity using float-type switches in each fuel tank; these switches operate independently of the EIS fuel quantity system.

a bar—representing the amount of fuel in the left and the right tanks, as shown in figure 4. One bar is equal to about 7.17 gallons or 48.3 pounds of fuel.[33] The 28 bars are based on the 1,352-pound usable fuel capacity for each tank and are arranged in a vertical arc alongside an incremental indication of available fuel—a full tank is indicated by the letter F; the numbers 1, 2, and 3 correspond to a tank that is one-quarter, one-half, and three-quarters full, respectively; and the zero indicates a tank that is empty. As explained in the PC-12 AFM, normal system operation is indicated by the left and the right fuel quantity gauges remaining within a two-bar differential. The other EIS fuel quantity indicator displays numerically the total available fuel quantity in both tanks (in pounds), the fuel flow rate (in pounds per hour), and the total amount of fuel used (in pounds) since the beginning of the flight. The EIS is further discussed in section 1.6.3.

Figure 4. Fuel quantity indicator.

[33] One gallon of jet fuel equals 6.73 pounds.

Lateral fuel symmetry is maintained automatically by the EIS when the pump switches are set to the AUTO position.[34] The EIS monitors fuel quantity in the left and right tanks to detect fuel imbalances exceeding about 10.5 gallons or 70 pounds. When such imbalances occur, the fuel boost pump in the tank with the higher fuel quantity operates until the fuel levels in both tanks are sensed to be equal.[35] This fuel balancing system is designed to automatically correct fuel imbalances of up to 40 gallons or about 270 pounds (displayed as a six-bar differential on the fuel quantity indicator).

If the fuel quantity differential between the two fuel tanks were to exceed 270 pounds (which is about 20 percent of each wing's total fuel capacity), automatic fuel balancing would be inhibited. The 270-pound system limit was designed to prevent the system from operating with either a failure of the fuel quantity measurement system (which could result in an under- or over-representation of the actual fuel quantity in one wing tank) or a fuel leak in one wing.

The Pilatus PC-12 AFM, section 2, Limitations, dated March 30, 2001, instructed pilots to monitor the fuel quantity gauges during normal operation (that is, with the fuel boost pump switches in the AUTO position) to verify that the fuel was balanced laterally. The AFM stated that the maximum fuel imbalance for the PC-12 was 26.4 gallons or about 178 pounds and a maximum of three bars on the fuel quantity indicator. If the fuel balancing system were unable to maintain lateral fuel symmetry (as indicated by a fuel quantity differential that exceeded three bars) or if automatic fuel balancing were inhibited (as indicated by a fuel quantity differential that exceeded six bars), fuel symmetry could be maintained by manually selecting the fuel boost pump switch to the ON position for the tank with the higher fuel quantity. Once a balanced fuel condition was restored, the fuel boost pump would be turned off (by returning the switch to the AUTO position). The AFM further instructed the pilot to monitor the fuel quantity indicator to ensure continued fuel symmetry during the remainder of the flight.

1.6.2 Central Advisory and Warning System

The airplane's CAWS provided warning, caution, and advisory indications to the pilot(s). The CAWS displayed up to 48 individual indications using colored light-emitting diodes. (Three of the 48 individual indications were intentionally left blank by the CAWS manufacturer.) Illumination of a red warning light indicated a condition that required an immediate corrective action by the pilot. Illumination of an amber caution light indicated a condition that required the pilot's attention but not an immediate corrective action. Illumination of a green advisory light indicated that a system was operational. The CAWS display was located in the lower center section of the instrument panel. Figure 5 shows the CAWS indications and the color in which each indication would be displayed to the pilot.

[34] The EIS receives input from the four fuel probes located in the wing fuel tanks.

[35] Fuel boost pump activation is delayed by 1 minute to ensure that the activation is not a spurious occurrence resulting from turbulence.

Figure 5. Central advisory and warning system display.

A red CAWS warning light was accompanied by illumination of the red master WARNING light and an audio message announcing the specific warning. An amber caution light was accompanied by illumination of the amber master CAUTION light and a gong sound. The aural annunciations associated with the master WARNING and CAUTION lights sounded through the overhead speaker and/or headset(s). The master WARNING and master CAUTION lights were located on the instrument panel directly in front of the pilot(s). Pushing the master WARNING or CAUTION light would extinguish it, but the CAWS warning or caution light would remain illuminated in red or amber until the situation was resolved.

As shown in figure 5, among the CAWS indications were amber cautions for low fuel quantity ("L FUEL LOW" and "R FUEL LOW") and low fuel pressure ("FUEL PRESS") and green advisories for fuel boost pump operation ("L FUEL PUMP" and "R FUEL PUMP"). According to the PC-12 AFM, section 7, Airplane and Systems Description, dated February 28, 2005, a low fuel quantity occurs when the fuel level in a tank is less than 20 gallons (133 pounds), and low fuel pressure occurs when fuel system pressure is less than 2 psi. The "L FUEL PUMP" and "R FUEL PUMP" advisories showed that power was being relayed to the respective pump and was thus an indirect indication of boost pump operation. The CAWS was not configured with a direct indication of boost pump operation or output. As a result, pilots are required, as part of the AFM Before Starting Engine checklist, to manually activate each boost pump switch and audibly verify pump operation before each flight.

The CAWS central advisory control unit contained nonvolatile memory on flash memory chips. Nonvolatile memory data downloaded from the airplane's CAWS central advisory control unit contained information for 480 flights made during the 2 years before the accident. The data showed similarities among the flight from REI to VCB, the accident flight (OVE en route to BZN with a divert to BTM),[36] and a flight that occurred in October 2007. Section 1.16.2 discusses these data in detail.

[36] For the flight from VCB to OVE on the day of the accident, no fuel boost pump advisories were logged.

1.6.3 Engine Instrument System

The EIS displayed engine and other systems information (including fuel quantity, as previously shown in figure 4). The EIS display was located in the lower center section of the instrument panel above the CAWS display. Among its other functions, the EIS recorded engine trend information as well as information on engine parameter limits that were exceeded during the engine's run time.[37]

Examination of EIS data showed that engine trend information was recorded during two periods for the flight from REI to VCB and the accident flight leg. (No engine trend data were recorded for the flight from VCB to OVE because the airplane did not reach the 10,000-foot minimum altitude required for such data to be recorded.) For the flight from REI to VCB, the EIS recorded the average total air temperature as -24º C between 0911:55 and 0916:52 and between 0923:53 and 1005:05. At those times, the airplane was operating at FL260 and FL220, respectively. For the accident flight leg, the EIS recorded the average total air temperature as -32º C between 1237:03 and 1405:24 and -10º C between 1418:33 and 1418:52. At those times, the airplane was operating at FL250 and 15,000 feet, respectively.[38] The average total air temperature corrected for airspeed resulted in an average outside air temperature of -32º C for the flight leg from REI to VCB and -40º C (at cruise altitude) for the accident flight leg.

In addition, the EIS recorded flight summary information for each flight, including the maximum value reached for each engine parameter during the flight. Summary data for the flight from VCB to OVE showed that the airplane operated at a maximum altitude of 6,000 feet,[39] where the outside air temperature was about -4º C (according to archived meteorological data).

1.6.4 Pilatus Fuel System Emergency Procedures

Section 3 of the AFM, Emergency Procedures, dated February 28, 2005, included the procedures at the time of the accident for low fuel pressure, a fuel pump failure, and an auto fuel balancing failure. On June 30, 2010, the procedures for low fuel pressure and an auto fuel balancing failure were revised, and procedures for low fuel quantity were added. Sections 1.6.4.1 and 1.6.4.2 describe the emergency fuel system procedures in effect at the time of the accident and after the accident, respectively.

1.6.4.1 Emergency Procedures in Effect at the Time of the Accident

The emergency procedure for low fuel pressure stated that the condition was indicated on the CAWS by a FUEL PRESS caution. The procedure further stated the following:

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[37] The only engine parameter exceedance recorded during the flights on the day of the accident was propeller overspeed at engine start. Pilatus stated that a software "bug" in the EIS recording system would cause this parameter to be recorded, even though no such exceedance actually existed.

[38] No engine trend data were recorded from 0916:53 to 0923:52 (during the flight leg from REI to VCB) and from 1405:25 to 1418:32 (during the accident flight leg) because the predefined set of parameters was not stable for more than 2 minutes.

[39] No radar data were available for the flight leg from VCB to OVE.

1. Power: reduce to minimum to sustain flight.

2. Fuel pumps: ON.

NOTE: monitor the fuel state if the left and right fuel pumps are continuously on. If necessary, set the fuel pumps on the emptier side to AUTO.

3. Aircraft: land as soon as possible. Retain glide capability to landing area if possible.

NOTE: Fuel low pressure will normally cause the fuel pumps to come on automatically. In this case, the indication is both fuel pumps running continuously, cycling off and on every 10 to 15 seconds (as shown by the L FUEL PUMP and R FUEL PUMP advisories).

4. Fuel pumps: ON.

5. Aircraft: descent to warmer air. A possible cause is the fuel filter blocked with ice crystals.

The procedure for a fuel pump failure, as indicated by the absence of a FUEL PUMP advisory when the fuel pump switch was in the ON position, directed the pilot to reposition the fuel boost pump switch to the AUTO position and reset the pump's circuit breaker. If the procedure was unsuccessful, the pilot was instructed to monitor the fuel state and refer to the auto fuel balancing failure procedure if a fuel imbalance developed.

The procedure for an auto fuel balancing failure, as indicated when the EIS fuel quantity gauges showed a difference of three or more bars between the left and the right fuel tanks without the automatic operation of the fuel balancing system, was the following:

1. Fuel pump (fuller side): ON.

2. Fuel state: monitor. If difference cannot be balanced, land as soon as practical.

3. When fuel balanced: fuel pump AUTO.

1.6.4.2 Emergency Procedures in Effect After the Accident

The revised procedure for low fuel pressure states that cycling of the CAWS advisory FUEL PUMP on and off every 10 seconds is an indication of low fuel pressure (in addition to the CAWS caution FUEL PRESS, which was the sole indication cited in the earlier procedure). The procedure was further revised as follows:

1. Power: reduce to minimum to sustain flight.

2. Fuel pumps: ON.

3. Fuel state: monitor.

If the difference between the left and the right fuel tanks is two or more segments:

4. Fuel pump for the emptier side: AUTO.

5. Fuel state: monitor.

When fuel is balanced:

6. Fuel pumps: ON.

7. Aircraft: descent to warmer air.

NOTE: A possible cause is the fuel filter blocked with ice crystals.

8. Fuel pumps: AUTO.

If failure conditions remain:

9. Fuel pump(s): ON.

10. Aircraft: land as soon as possible. Always retain glide capacity, if possible, to the selected airfield in case of total engine failure.

The new procedure for a low fuel quantity states that this condition is indicated by either the CAWS "L FUEL LOW" or "R FUEL LOW" caution (or both cautions). The procedure is as follows:

1. Fuel indications: check.

If a fuel leak from one wing is suspected:

2. Aircraft: carry out suspected fuel leak procedure.

If no fuel leak is suspected and both fuel low quantity cautions are on:

3. Fuel pumps: ON.

4. Power: reduce to minimum to sustain flight.

5. Aircraft: land as soon as possible. Always retain glide capability, if possible, to the selected landing airfield in case of total engine failure.

The revised procedure for an auto fuel balancing failure addresses the separate actions to be taken on the ground and during flight in response to this failure. The revised procedure states the following:

A. ON GROUND

1. Left and right fuel indications: Check for difference.

WARNING: If there is a difference of four or more segments between the left and the right fuel tanks do not take off.

If fuel pump on fuller side is not running:

2. Fuel pump (fuller side): ON.

3. Fuel state: monitor.

If difference cannot be balanced:

4. Aircraft: do not take off.

When fuel is balanced:

5. Fuel Pump: AUTO.

B. IN FLIGHT

1. Left and right fuel indications: check for difference.

CAUTION: If there is a difference of three or more segments between the left and the right fuel tanks, a possible aileron deflection would be required for wings-level flight, especially at low speed.

If a fuel leak from one wing is suspected:

2. Aircraft: carry out suspected fuel leak procedure.

If no fuel leak is suspected:

3. Fuel pump circuit breaker on fuller side (battery or generator 1 bus bar): reset.

4. Fuel pump on fuller side: ON.

5. Fuel pump circuit breaker on emptier side (battery or generator 1 bus bar): pull.

6. Fuel state: monitor.

If difference cannot be balanced:

7. Aircraft: land as soon as possible.

NOTE: If a prompt landing is not possible, keep high indicated airspeed to nearest airfield and consider burning off fuel until the fuel imbalance is not more than five segments for landing. Use flaps up to keep approach speed high.

If fuel is balanced:

7. Fuel pump circuit breakers: reset.

8. Fuel pumps: AUTO.

1.6.5 Fuel System Certification and Testing

1.6.5.1 Fuel System Testing

Pilatus conducted certification testing on the PC-12 to demonstrate compliance with 14 CFR 23.951(c), “Fuel System, General,” which stated the following:

> Each fuel system for a turbine engine must be capable of sustained operation throughout its flow and pressure range with fuel initially saturated with water at 27° C and having 0.75 cc [cubic centimeters] of free water per gallon added and cooled to the most critical condition for icing likely to be encountered in operation.[40]

The testing, which was conducted using a simulation of the aircraft fuel system housed in a cooling chamber,[41] demonstrated operation throughout the range of temperatures that the PC-12 was expected to encounter during its service life. Pilatus Engineering Report ER 12-28-01-001 (dated July 1993), provided the following test results:

> At the start of the first 30 minute, 700 [pounds per hour] run, fuel temperature was -5 degrees Celsius (C). As the fuel temperature dropped through -8/-10 degrees C, pressure fluctuations were observed at the air separator tank and [the low-pressure engine-driven fuel pump] output pressure indicators. On reaching -20 degrees C it was not possible to maintain the then-selected 100 [pounds per hour] flow at adequate pressure required for normal engine operation.

According to Pilatus’ report, the fuel boost pumps were on at that point during the test, but they were not able to restore normal pressure and flow. As a result, the test was prematurely terminated. Examination of the fuel filter revealed that it was “blocked with ice particle buildup,” which restricted fuel flow through the filter.

A second test was performed using the same aircraft fuel system except that a FSII with a concentration of 0.08 percent by volume was added to the fuel. The test results showed that fuel flow and pressure remained consistent to an ambient temperature of -53º C (with a fuel temperature of -48º C). The fuel filter was examined after the test and was found to be partially obscured, on the topmost surface of the filter disc stack, by a thin film of “water/ice slush,” which did not restrict the passage of fuel through the filter. The fuel boost pumps did not operate during this test.

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[40] The PC-12 fuel system was based on the PC-7 and PC-9 fuel systems. (The PC-7 and PC-9 are military training airplanes.)

[41] The system used for this test did not incorporate a fuel bypass valve, which is part of the fuel system installed on PC-12 production airplanes.

1.6.5.2 Fuel Boost Pump Testing

The accident airplane was equipped with Lear Romec model RR53710K electrically-driven fuel boost pumps. (Lear Romec is now a division of Crane Aerospace and Electronics of Elyria, Ohio.) Qualification testing, as detailed in Lear Romec Qualification Test Report TR-3556 (dated January 1995), was conducted to verify that the "K" model fuel boost pump met the requirements of the original fuel boost pump, referred to as the "B" model.

The qualification testing of model K fuel boost pumps did not include any cold jet fuel testing; all of the tests were performed with jet fuel temperatures above 0º C.[42] In addition, the qualification testing of model B fuel boost pumps did not include any cold temperature testing with jet fuels.[43]

The NTSB and Crane Aerospace conducted testing on two PC-12 model K fuel boost pumps after the accident. Information about the specific tests and the results of the tests is discussed in section 1.16.1.

1.6.5.3 Fuel Asymmetry Testing

Pilatus tested the PC-12 to ensure compliance with 14 CFR 23.23, "Load Distribution Limits," for normal flight conditions, as documented in Pilatus Engineering Report ER 12-03-80-002 (dated February 1994). This report showed that the PC-12 was tested beyond the AFM's maximum fuel imbalance limit of 178 pounds. Specifically, with the PC-12 loaded at the most critical weight and center of gravity and with the most critical operating condition (landing gear extended, flaps extended to the landing position, and engine power on), both wings-level and turning stall flight tests were performed with a fuel imbalance between 240 and 380 pounds. According to Pilatus, all of these tests were flown successfully, and the pilot did not report any problems performing the maneuvers. Pilatus further indicated that, in terms of aircraft handling, the first indication of fuel asymmetry was the need to increase the amount of aileron trim, which occurred with a fuel imbalance of 130 pounds, or about 10 percent of the total fuel capacity in one tank (displayed as a two- to three-bar differential).

1.6.5.4 Fuel System Hazard Assessment

Pilatus conducted a fuel system hazard assessment to comply with the requirements of 14 CFR 23.1309, "Equipment, Systems, and Installations."[44] Sections (a)(1) and (2) of the regulation stated the following:

[42] Pilatus Specification ESM-12-SPEC-171, dated November 1992, indicated that the range of operating environment (outside air) temperatures for PC-12 fuel boost pumps was -65° to 55° C, even though the fuel boost pumps had not been tested with jet fuel temperatures below 0° C.

[43] The performance of the fuel system with model B fuel boost pumps was documented in Lear Siegler (Romec Division) Engineering Test Report TR-2198 (dated October 1977). The report stated that fuel system testing was conducted using JP-4 fuel and simulated JP-5 fuel. (JP-4 and JP-5 are jet propellant fuels used by the military. They are similar to civilian aircraft Jet B fuel but have lower flash points and include a FSII.) The JP-4 fuel was heated to 43° C. To simulate JP-5 fuel, a fuel oil was cooled to -23° C to replicate the fuel's kinematic viscosity at -45° C.

[44] This regulation became effective on November 26, 1990, and was subsequently revised on February 9, 1996.

> When performing its intended function, [each item of equipment, each system, and each installation] may not adversely affect the response, operation, or accuracy of any…equipment essential to safe operation; or…other equipment unless there is a means to inform the pilot of the effect.
>
> In a single-engine airplane, [each item of equipment, each system, and each installation] must be designed to minimize hazards to the airplane in the event of a probable malfunction or failure.
>
> Section 23.1309(b) stated, in part, the following:
>
> The design of each item of equipment, each system, and each installation must be examined separately and in relationship to other airplane systems and installations to determine if the airplane is dependent upon its function for continued safe flight and landing and, for airplanes not limited to VFR conditions, if failure of a system would significantly reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions.[45]

Further, section 23.1309(b)(1) stated that each item of equipment, each system, and each installation "must perform its intended function under any foreseeable operating condition."

Operational experience and reliability data from Pilatus aircraft with the same fuel system as the PC-12 were used to support the fuel system hazard assessment. Several system fault outputs and failure conditions were considered during the assessment, and the assessment results were detailed in Pilatus Engineering Report ER12-28-00-001 (dated September 1993).

One condition that was considered in the fuel system hazard assessment was an excessive fuel imbalance between both wing fuel tanks. Regarding this condition, the assessment stated, "the difference in fuel weight will produce a rolling moment on the aircraft. This moment may be counteracted by changing the trim setting and the failure condition may be removed by differential operation of the booster pumps." The assessment further stated, "in the event of a major fuel imbalance which cannot be corrected by operating the booster pumps, the rolling moment may become too large to be counteracted by trimming and it may be necessary to amend the planned mission."

An addendum to the assessment (which was also included in Pilatus Engineering Report ER 12-28-00-001) further considered the effects of an excessive fuel imbalance between both wing fuel tanks. According to the addendum, if a fuel imbalance between both wing fuel tanks exceeded 25 percent of the full fuel tank load, "the resulting rolling moment cannot be corrected by trimming alone and the control [wheel] must be used." The addendum cautioned that this scenario would increase pilot workload and decrease the airplane's safety margin in the event of a maneuver requiring higher-than-usual levels of piloting skill.

[45] Section 23.1309(b) continued, "each item of equipment, each system, and each installation identified by this examination as one upon which the airplane is dependent for proper functioning to ensure continued safe flight and landing, or whose failure would significantly reduce the capability of the airplane or the ability of the crew to cope with adverse operating conditions, must be designed to comply with…additional requirements." These requirements were detailed in paragraphs (1) through (4) of section 23.1309(b).

1.6.6 Service Bulletin Information

Two fuel boost pumps that Pilatus forwarded to Lear Romec for testing related to "current draw"[46] were subjected to acceptance test procedures at nominal room temperatures. Both fuel boost pumps passed the acceptance test procedures with no anomalies except that the armature end play[47] of the pumps was less than the required end play measurement (0.005 to 0.015 inch). Lear Romec conducted additional testing, using cold Jet A fuel with a FSII added, to further evaluate the performance of fuel boost pumps. The results of the testing showed that (1) cold temperature operation decreased the armature shaft end play of the fuel boost pumps and (2) with proper armature shaft end play, the fuel boost pumps were capable of operating at fuel temperatures down to -54º C. (This test did not evaluate the operation of the fuel boost pumps during an extended period of time using cold Jet A fuel without a FSII added.)

Pilatus issued Service Bulletin (SB) 28-008 in June 2001 to require an inspection of the armature shaft end play and the replacement of fuel boost pumps with an armature end play that measured less than 0.005 inch. The SB indicated that insufficient end play in the fuel boost pump armature could potentially cause the pumps, at low temperatures, to use more current than usual, which would cause the circuit breaker to open and prevent operation of the pump. The SB indicated that affected pumps had nonsequential serial numbers ranging from B4516 to B5116 and specified that the armature shaft end play inspection of these pumps be accomplished using the procedures detailed in Lear Romec SB RR53710K-20-001 (dated February 2001). The Lear Romec SB stated that fuel boost pumps that were inspected according to the SB and found to be acceptable were to be marked with an "A" behind the serial number on each pump's data plate.

Even though new-production fuel boost pumps were not subject to either the Pilatus or the Lear Romec SBs, the pumps were subject to an armature shaft end play inspection. The accident airplane's fuel boost pumps had serial numbers B5159A and B5161A. (The "A" designation for new-production fuel boost pumps indicated that the pumps' armature shaft end play was measured and verified to be within the specified tolerance.) A review of maintenance log and service invoice records indicated that neither of the fuel boost pumps had been replaced since the time that they were installed on the airplane.[48]

[46] Fuel boost pumps require a specific amount of electrical current (referred to as "current draw" and measured in amps) to operate. When the amount of electrical current is exceeded, the fuel boost pump circuit breaker trips. Pilatus reported that, during an August 2000 PC-12 delivery flight, a fuel boost pump circuit breaker tripped when the fuel boost pump was activated. At that time, the airplane was operating at FL300, where the outside air temperature was -40º C. In response to this and other related events, Pilatus removed the individual fuel boost pumps from their respective airframes and returned them to Lear Romec for testing. According to Lear Romec Test Report TR-4277 (dated April 2001), the increase in the amount of current draw was primarily the result of an increase in density of the cold Jet A fuel.

[47] In this case, end play measures the tolerance for movement of the armature shaft (that is, the distance that the shaft is allowed to travel before it becomes restricted).

[48] The Pilatus PC-12 Maintenance Manual does not specify a life limit for the fuel boost pumps.

1.7 Meteorological Information

BTM has an automated weather observing system (AWOS), which reported the following conditions surrounding the time of the accident:[49]

- About 1353, wind from 320° at 10 knots, visibility 10 miles, a few clouds at 4,400 feet, ceiling overcast at 8,000 feet, temperature 7° C, dew point temperature -3° C, and altimeter 29.57 inches of mercury (Hg).
- About 1453, wind from 300° at 8 knots, visibility 10 miles, ceiling broken at 6,500 feet, temperature 7° C, dew point temperature -3° C, and altimeter 29.56 inches of Hg.

BZN has an automated surface observing system (ASOS), which reported the following conditions surrounding the time of the accident:

- About 1356, wind from 290° at 7 knots, visibility 10 miles, sky clear below 12,000 feet, temperature 14° C, dew point -1° C, and altimeter 29.54 inches of Hg.
- About 1456, wind from 350° at 8 knots, visibility 10 miles, ceiling broken at 5,500 feet, temperature 14° C, dew point -1° C, and altimeter 29.52 inches of Hg.

Information about the outside air temperature during the flights would have been presented to the pilot on the EIS. Pilot reports of the area surrounding the accident site indicated light to moderate turbulence over Idaho and Montana, mountain wave activity over Montana, and light to moderate rime and mixed icing conditions below FL190. The pilots of a Beechcraft King Air turboprop airplane that was descending into BTM reported at 1433 (about 1 minute after the accident) light to moderate rime icing conditions but commented that the icing conditions were normal for flight in the mountains and that the icing could be controlled by the airplane's deice boots (which were similar to those installed on the accident airplane).

1.8 Aids to Navigation

No problems with any navigational aids were reported.

1.9 Communications

No technical communications problems were reported.

1.10 Airport Information

BTM had two runways: runway 15/33 was 9,001 feet long and 150 feet wide, and runway 11/29 was 5,100 feet long and 75 feet wide. The airport was not serviced by an ATC tower. Approach and departure services were provided on a continuous basis by the Salt Lake ARTCC.

[49] Visibility is expressed in statute miles. Cloud cover and cloud ceiling are expressed in feet agl.

BTM has an elevation of 5,550 feet and is surrounded by mountainous terrain, as shown previously in figure 2. BTM is in a valley located about 1 1/2 miles west of a mountain range that rises to an elevation of 8,000 feet to the east of the airport.[50] The mountain range located about 13 miles south of BTM includes terrain that rises to an elevation of 10,000 feet. This terrain, which is generally oriented south to north to the west of BTM, decreases in elevation to 8,200 feet about 13 miles southwest of BTM and 6,000 feet about 5 miles west of the airport, and the terrain rises to an elevation of 9,400 feet about 17 miles southwest of the airport. The terrain located 15 miles north of BTM rises to an elevation of about 7,500 feet.

1.10.1 Air Traffic Control Information

The Salt Lake ARTCC was responsible for providing ATC services for a 365,000-square mile area that encompassed numerous airports. The facility averaged about 1.4 million operations per year. The ARTCC was equipped with a surveillance weather radar system.[51]

After the accident, the NTSB interviewed two of the sector 6 controllers who handled the accident airplane. The controller at the sector 6 position was responsible for airspace from the surface to 60,000 feet in Montana, Wyoming, and parts of Idaho.

The first sector 6 controller stated that he first became aware of the airplane during a briefing from the previous sector 6 controller. At that time, the airplane was en route to BZN at FL250. The controller stated that he noticed that the airplane (after it turned toward BTM) had begun descending from FL250 before the pilot was cleared for the descent. The controller stated that he did not see any aircraft or terrain that would have presented a conflict, so he decided not to say anything to the pilot and instead instructed him to descend at his discretion to 14,000 feet.

The controller stated that the pilot did not seem confused or disoriented after he repeated his request to divert to BTM. The controller also stated that the airplane's rate of descent did not seem erratic. Further, the controller indicated that no low-altitude alert was generated for the airplane after it descended (without clearance) below 12,200 feet.[52]

About 1419, the controller was relieved from the position as part of a normal shift rotation. The controller indicated that, during the relief briefing, he did not advise the next controller that the pilot had been instructed to report when he had obtained the weather for BTM.

The second sector 6 controller stated that, at the time of the relief briefing, the airplane was en route to BTM and was descending to an altitude of 14,000 feet. The controller stated that

[50] In this paragraph, distances are expressed in statute miles, and terrain elevations are approximations.

[51] Weather radar echoes are measured in decibels, with light precipitation measuring less than 30 decibels and moderate precipitation measuring between 30 and 40 decibels. The weather information along the airplane's route of flight about the time of the accident showed no intensities measuring more than 30 decibels. Because en route radar systems presented weather information only in three intensities—moderate, heavy, and extreme—the light precipitation measuring less than 30 decibels would not have been displayed on the ARTCC's radar system.

[52] A low-altitude alert provides controllers with an aural and a visual warning when aircraft equipped with a mode C transponder are operating below a predetermined minimum safe altitude. In this case, the system that generated the alerts did not sense a potential conflict between the airplane's descent rate and the terrain below the airplane.

he requested the weather at BTM and learned that VFR conditions existed with ceilings broken from 5,000 to 6,000 feet agl and overcast at 10,000 feet agl. The controller did not recall seeing any weather depicted on his weather display, and he assumed that the pilot had received information about the current weather at BTM.

After the pilot reported BTM in sight and canceled his IFR flight plan, the controller instructed the pilot to squawk VFR. The controller stated that he tried to contact the pilot about 1 minute later when he noticed that the airplane's previously assigned discrete transponder code had not changed to transponder code 1200. The controller thought that the pilot might not have responded because he had selected the BTM advisory frequency.

The first sector 6 controller stated that he could usually remember whether a pilot had received weather information for the destination airport but that he had a personal practice of placing a check mark on the flight progress strip to indicate that information.[53] The second sector 6 controller stated that he did not mark flight progress strips to note this information.

1.10.2 Air Traffic Control Procedures

FAA Order 7110.65, paragraph 4-7-10, "Approach Information," stated the following in paragraph (a):

> Both en route and terminal approach control sectors shall provide current approach information to aircraft destined to airports for which they provide approach control services. This information shall be provided on initial contact or as soon as possible thereafter…. For pilots destined to an airport without ATIS [automatic terminal information service], items 3-5 below may be omitted after the pilot advises receipt of the automated weather; otherwise, issue approach information by including the following:
>
> 1. Approach clearance or type approach to be expected if two or more approaches are published and the clearance limit does not indicate which will be used.
>
> 2. Runway if different from that to which the instrument approach is made.
>
> 3. Surface wind.
>
> 4. Ceiling and visibility if the reported ceiling at the airport of intended landing is below 1,000 feet or below the highest circling minimum, whichever is greater, or the visibility is less than 3 miles.
>
> 5. Altimeter setting for the airport of intended landing.

In addition, paragraph 4-7-10 noted the following information in the phraseology section:

[53] FAA Order 7210.3, "Facility Operations and Administration," paragraph 6-1-6, "Flight Progress Strip Usage," noted, "posting control information onto the flight progress strip serves as an important nonverbal communications tool between members of the control team."

> Aircraft destined to uncontrolled airports, which have automated weather data with broadcast capability, should monitor the ASOS/AWOS frequency to ascertain the current weather at the airport. The pilot should advise the controller when he/she has received the broadcast weather and state his/her intentions.

1.11 Flight Recorders

The accident airplane was neither equipped nor required to be equipped with a cockpit voice recorder (CVR) or a flight data recorder (FDR).

1.12 Wreckage and Impact Information

The entire debris field was contained within a cemetery located west of runway 33 at BTM. The initial impact point was a ground scar that was 23 feet wide, 9 feet long, and 16 inches deep. The wreckage was scattered along a path with a magnetic heading of 245º from the initial impact point. Examination of the wreckage revealed that the airplane had sustained severe fragmentation, deformation, and significant thermal damage, with more severe fire damage found on the left side of the airplane compared with its right side.

The fuselage was found in three main pieces. The first piece consisted of the engine, its mount, and the forward fuselage. The cockpit had been partially destroyed by fire. The second fuselage piece consisted of the area encompassing the overwing emergency exit (on the right side of the airplane). The cabin had been destroyed by impact forces and fire. The third fuselage piece consisted of the empennage from the rear pressure bulkhead to the aft-most portion of the tail. The tail came to rest on its left side, and the horizontal stabilizer was sheared at its hinge points. The tail was the wreckage piece that was located closest to the initial impact point (about 20 feet away). The fuselage wreckage that was forward of the tail came to rest on its right side on a magnetic heading of 290º.

The engine showed severe impact damage and fire damage on those portions located near the firewall. The first-stage compressor blades showed circumferential rubbing and deformation opposite the direction of rotation. The blade leading edges showed circumferential nicks, gouges, and tears that were consistent with ingested debris. The compressor turbine had circumferential rubbing at both the upstream and downstream sides, and the disc hub showed heavy circumferential rubbing. The first-stage power turbine blade airfoils were fractured at their roots, and all of the blade roots showed deformation opposite the direction of rotation and heavy mechanical damage. Several blade tips were separated, and recovered portions of the blade tips showed circumferential rubbing and features consistent with overload fracture. No indications of fatigue or other progressive fracture mechanisms were found. The second-stage power turbine blades were fractured with deformation opposite the direction of rotation and heavy mechanical damage. The exhaust duct showed severe compression deformation and no indications of metal being expelled from the exhaust.

The propeller was severely fragmented, and all four propeller blades had separated. Two of the blades exhibited severe damage. One of these blades had numerous deep gouges and showed evidence of bending and chordwise scratching. The other blade was torn chordwise, and a separated blade portion showed gouging, tearing, and chordwise scratching. The two remaining blades exhibited minor damage. One of these blades had leading edge gouges, and both of these blades had some chordwise paint scoring. The propeller cylinder showed a deep gouge that was consistent with contact with the blade counterweight. The measured position of this gouge was consistent with a pitch position in the operating range at impact.

The cockpit switch for the deice system was not located in the wreckage, but the deice boot timer was found intact. Testing of the timer found that a deice valve solenoid for a wing outboard deice boot was receiving power and that the deice system was not between inflation and deflation cycles when the airplane's electrical system lost power.[54]

The left wing showed heavy damage at its wing root, and the largest wing piece recovered was the rear spar. The right wing had sheared at its wing root and was relatively intact compared with the left wing. The left main landing gear was torn from the left wing and was found at the initial impact point. The right main landing gear had separated from its main attachment points and was found aft of the right wing, and the right main landing gear actuator was found in the extended position. A gravestone located aft of the right main landing gear showed a rubber transfer mark that was consistent with contact with the right main landing gear tire. The nose landing gear had separated from the airframe and was found about 10 feet to the left of the forward portion of the fuselage. Continuity of the elevator, rudder, and aileron flight control systems was verified from the cockpit controls to the flight control surfaces.

The trim actuators for all three control surfaces were found in the wreckage. The actuators were a jackscrew design and were not susceptible to movement by impact forces. Examination of the aileron and rudder trim actuator jackscrews found that their measured positions correlated to full right-wing-down (RWD) aileron trim[55] and full airplane-nose-left (ANL) rudder trim. The pitch trim actuator jackscrew was within its normal measurement range and indicated orientation toward an airplane-nose-down position.

1.12.1 Fuel System

The only recovered component from the left fuel boost pump was the impeller housing. Examination of the impeller by the NTSB Materials Laboratory found two axial deformation marks on the through-hole; the deformation marks extended the entire length of the through-hole and were spaced 0.171 inch apart from each other. The spacing was consistent with the 0.170-inch width of the parallel flats on the drive shaft. The impeller vanes were fractured or cracked, and some exhibited deformation marks.

[54] For the PC-12, the airframe deice system is activated separately from the propeller deice system and the engine inertial separator. A CAWS "PUSHER ICE MODE" advisory is logged when both the engine inertial separator and the propeller deice system are active. For the accident airplane, CAWS data showed that the airframe deice system was turned on about 2 hours 3 minutes into the flight and remained on through the time of the last CAWS entry for the flight, which was logged 20 minutes later. Also, although the inertial separator was found in the open position, CAWS data showed that no PUSHER ICE MODE advisory had been logged.

[55] The actuator's internal potentiometer resistance values were measured; these measurements correlated to full extension of the actuator.

The entire right fuel boost pump was recovered but showed extensive fire and heat damage. Examination of the right fuel boost pump impeller and pump housing by the NTSB Materials Laboratory found that the impeller had expanded in size (as a result of the postaccident fire) to fill the housing, with the center of the impeller expanded into the suction-side inlet and the edge of the impeller expanded into the pressure-side outlet. The right fuel boost pump impeller vanes could not be examined for fractures, cracks, and deformation marks because of the heat damage to the impeller. Deformation marks on the right fuel boost pump housing and metal transfer on the right pump drive shaft were consistent with contact between the drive shaft and the housing through-hole. The deformation marks extended about one-half of the length of the through-hole and were spaced 0.166 inch apart from each other. This spacing was also consistent with the 0.170-inch width of the parallel flats on the drive shaft.

The postimpact rotational orientation of the left and right fuel boost pump impellers and their respective drive shafts was estimated from photographs of the left and right boost pumps as recovered. The estimates for the impellers were 222º ± 3º (left) and 268º ± 3º (right). The orientation of the drive shaft contact marks on the respective through-hole in the left and right fuel boost pump housing was estimated to be 220º (left) and 224º (right).

The fuel filter bypass valve was found mostly intact, but the differential pressure indicator (which extends a red button when a sufficient differential pressure bypasses the fuel filter) had separated. Examination of the bypass valve by the NTSB Materials Laboratory found that the differential pressure indicator was in the off position. (This position was not a reliable indication that a bypass condition did not occur because it is possible that impact forces could have dislodged the red button from the differential pressure indicator and reset the indicator to the off position.)

Portions of the fuel lines from the supply, motive flow, and fuel control return sections were identified, but no useful information could be obtained because of the extensive impact and fire damage. Examination of other recovered fuel system components revealed no evidence of any preimpact mechanical anomalies.

1.13 Medical and Pathological Information

Postaccident toxicological testing was performed on specimens from the pilot by the FAA’s Civil Aerospace Medical Institute. Liver specimens tested negative for a wide range of drugs, including major drugs of abuse (marijuana, cocaine, phencyclidine, amphetamines, and opiates). Specimens from the pilot’s liver, lung, and bile tested negative for ethanol, but a very low level of ethanol was detected in the pilot’s muscle specimens. Information noted in the May 7, 2009, toxicological report indicated that the ethanol found in the pilot’s specimens was consistent with postmortem production.

1.14 Fire

No evidence or witness statements indicated an in-flight fire. The evidence indicated that the fire damage to the airplane occurred after the impact.

1.15 Survival Aspects

The two pilot and eight passenger seats were equipped with lap and shoulder harness restraints. Except for the pilot and the occupant of the right front seat, the NTSB was unable to determine the original seating positions for the occupants. The Forensic Science Division of the Department of Justice in Missoula, Montana, assigned the cause of death for all of the airplane occupants as blunt force injuries.

1.16 Tests and Research

1.16.1 Postaccident Fuel Boost Pump Testing

The NTSB conducted postaccident fuel boost pump testing at Crane Aerospace and Electronics' facility to determine the performance of exemplar model K pumps under operating conditions below 0º C. The tests were performed using three fuel conditions: jet fuel with no water or FSII added (the baseline test), jet fuel with water added, and jet fuel with water and a FSII added.

The two fuel boost pumps used during the tests, which were provided by Pilatus, had passed acceptance test procedures,[56] and the measurement of armature shaft end play (as discussed in section 1.6.6) was within limits. The test apparatus included a 50-gallon tank filled with Jet A fuel; a fuel boost pump; a check valve, which was provided by Pilatus and was identical to the check valve used in the accident airplane's fuel system; a fuel flow valve; pressure sensors; a flow meter; and a circulation pump, which controlled fuel temperature by routing fuel through a heat exchanger that was chilled with methanol.

For each fuel condition, both fuel boost pumps were run through a fuel calibration curve test (which is the same type of test that new fuel pumps are subjected to during acceptance testing) and an endurance test. The fuel calibration curves were derived by (1) measuring the fuel boost pump discharge pressure at 11 different fuel flow rates ranging from 0 to 3,000 pounds per hour[57] and (2) generating performance data curves for each of the three fuel conditions at temperatures of 0º, -15º, and -30º C. For the endurance test, the fuel temperature was stabilized at -30º C, the fuel boost pump discharge pressure was measured at a fuel flow rate of 900 pounds per hour, and the pump was cycling (that is, operating for 10 seconds and then turning off for 1 second).[58]

[56] The fuel boost pumps used during the tests were considered by Pilatus to be "unserviceable" and, as a result, were refurbished by Crane Aerospace before acceptance test procedures were performed.

[57] These fuel flow rates were 0, 400, 600, 800, 1,100, 1,200, 1,400, 1,600, 2,000, 2,400, and 3,000 pounds per hour (the last of which was the maximum fuel flow).

[58] One of the fuel boost pumps performed inconsistently during its initial test run (without water or a FSII added). The pump was removed from the test apparatus, disassembled, and visually inspected, and no assembly or mechanical problems were found. The motor brushes were found to be fully engaged with the commutator and were able to move freely. (The brushes ride on the commutator to conduct electrical power.) Further inspection found that one motor brush exhibited pitting and that brush material had collected on the commutator surface. The brushes and the commutator (and its armature portion) were then replaced, and subsequent testing of the pump produced normal results.

The fuel flow calibration curve test for the baseline condition (jet fuel with no water or FSII added) showed that both fuel pumps performed nominally. The endurance test (conducted at a temperature of -30º C) showed that the 900-pounds per hour fuel flow rate decreased progressively over time. The decrease in the flow rate was mitigated by adjusting the fuel flow valve in the first test pump and tapping the fuel flow valve in the second test pump to break away ice that had accumulated on the valve. Because these actions restored flow to about 900 pounds per hour, the reduced flow was likely the result of ice accumulation on the fuel flow valve rather than a problem with either pump's performance.[59]

For the test involving the condition of jet fuel with water, 270 cubic centimeters of water was added to the 50 gallons of fuel through a nozzle. The added water ensured that the saturation point of the fuel would be exceeded. The fuel flow calibration curve test for this fuel condition showed similar performance to the baseline test (no water or FSII added). The endurance test showed similar results to the baseline test except that the degradation of fuel flow rate occurred more quickly and additional adjusting and tapping on the fuel flow valve was necessary.

For the test involving the condition of jet fuel with water and a FSII, 200 cubic centimeters of Prist (the commonly known trade name for a FSII) was added to the fuel and water mixture using a nozzle that was directed to the inlet of the circulation (cooling) pump while it was operating. The fuel flow calibration curve test for this fuel condition showed similar performance to the previous two fuel conditions.[60] During the entire endurance test, the fuel flow rate remained relatively constant, and no adjusting or tapping on the valve was required to maintain the fuel flow rate.

1.16.2 Central Advisory and Warning System Data Extraction

As stated in section 1.6.2, nonvolatile memory data downloaded from the airplane's CAWS contained information about the airplane's 480 flights made during the 2 years before the accident.[61] For 477 of the 480 flights, the left and right fuel boost pumps activated a total of 29 times. (The CAWS logged events either as "activated" [on] or "cleared" [off].) These activations were consistent with the operation of the automatic fuel balancing system to laterally balance the fuel load. For the three remaining flights—REI to VCB (on the day of the accident), the accident flight leg (OVE en route to BZN with a divert to BTM), and a flight occurring on October 16, 2007 (from Cabo San Lucas to San Diego)—both fuel boost pumps activated 176, 337, and 260 times, respectively. No low fuel pressure cautions were logged during these and the 477 other flights for which CAWS data were available.

[59] The fuel flow valve used during the tests was not part of the PC-12 fuel system.

[60] Throughout the testing, none of the observed decreases in fuel pressure were associated with the Pilatus-supplied check valve.

[61] Examination of the recorded dates and times revealed discrepancies with known valid flight dates and times. Also, the recorded dates and times were not continuous throughout the time period covered by the log entries. According to Pilatus, the most likely cause for the discontinuity was a system clock battery change. (Maintenance record entries and maintenance invoices showed that the most recent system battery change occurred on September 20, 2007, after an annual inspection of the airplane.) To resolve the discrepancies regarding the recorded dates, calculations were made that resulted in a CAWS flight log that was generally consistent with the operator's flight log entries. The discrepancies regarding the recorded times were resolved to within 4 minutes 34 seconds, which was the difference between the total flight time recorded by the CAWS central advisory control unit and the time that the airplane was observed by radar during the accident flight.

For the flight from REI to VCB, the left and right fuel boost pumps began cycling about 1 hour 30 minutes into the flight. About 15 minutes later, the left fuel boost pump was on continuously, and the right fuel boost pump was off. The left fuel boost pump remained on continuously until the final entry for the flight, which was logged about 6 minutes later (at 1:51:35). Table 3 summarizes these data. No evidence indicated that the pilot sought maintenance assistance after the flight in response to the automatic operation of the fuel boost pumps.

Table 3. Central advisory and warning system data for flight from Redlands, California, to Vacaville, California.

Time in flight	CAWS message	Status
1:30:53	L FUEL PUMP	On—cycling
1:30:53	R FUEL PUMP	On—cycling
1:45:49	L FUEL PUMP	On—continuous
1:45:58	R FUEL PUMP	Off

For the accident flight leg, the CAWS data showed that, about 22 minutes into the flight, the right fuel boost pump was on continuously for 3 minutes 45 seconds. This time period was consistent with the average duration of the 29 fuel pump activations for automatic lateral fuel balancing. The left and right fuel boost pumps began cycling about 1 hour 13 minutes into the flight. About 1 hour 18 minutes into the flight, the left fuel boost pump was on continuously, and the right fuel boost pump was off. About 1 hour 21 minutes into the flight, the right fuel boost pump resumed cycling. After that time, the right fuel boost pump was cycling or was on continuously, and the left fuel boost pump was on continuously or was off. In addition, about 6 minutes before the final CAWS message (at 2:23:24), the "R FUEL LOW" caution was logged, indicating that 133 pounds of fuel remained in the right fuel tank. Table 4 shows the CAWS fuel system information logged during the accident flight leg.[62]

Table 4. Central advisory and warning system data for accident flight.

Time in flight	CAWS message	Status
0:22:04	R FUEL PUMP	On—continuous
0:25:49	R FUEL PUMP	Off
1:13:32	L FUEL PUMP	On—cycling
1:13:32	R FUEL PUMP	On—cycling
1:17:59	L FUEL PUMP	On—continuous
1:18:09	R FUEL PUMP	Off
1:21:05	R FUEL PUMP	On—cycling
1:52:08	R FUEL PUMP	On—continuous
1:52:18	L FUEL PUMP	Off
1:52:29	L FUEL PUMP	On—continuous
1:52:29	R FUEL PUMP	On—cycling
2:05:29	R FUEL PUMP	On—continuous
2:05:38	L FUEL PUMP	Off

[62] According to the manufacturer of the CAWS central advisory control unit, certain events were logged as "activated" only if the criteria prompting their activation were still met after a predefined time delay. For example, the FUEL PUMP advisory would be considered fully activated after a 0.3-second interval to display this advisory, and the FUEL LOW caution would become active after a 10-second interval to annunciate this caution aurally and visually. If an event that had been activated either became inactive or had cleared before the predefined time delays expired, a "cleared" status would be logged without a preceding "activated" status.

Time in flight	CAWS message	Status
2:08:36	L FUEL PUMP	On—continuous
2:08:36	R FUEL PUMP	On—cycling
2:10:35	R FUEL PUMP	On—continuous
2:10:44	L FUEL PUMP	Off
2:16:21	L FUEL PUMP	On—continuous
2:16:21	R FUEL PUMP	On—cycling
2:17:05	R FUEL LOW	On—continuous
2:17:10	R FUEL PUMP	On—continuous

During the last seconds of the flight, the "PUSHER" caution logged with a "cleared" status three times, but no "PUSHER" cautions were logged with an "activated" status at any time during the flight. (The PUSHER cautions are further discussed in section 1.16.2.1.) Also logged during the accident flight were an "A/P TRIM" advisory at 1 minute 36 seconds into the flight, indicating that the autopilot or yaw damper had been engaged;[63] an "A/P DISENG" caution about 1 hour 55 minutes into the flight, indicating that the autopilot had disengaged; and another "A/P TRIM" advisory about 1 hour 59 minutes into the flight, which indicated that the autopilot or yaw damper had again been engaged.

For the flight on October 16, 2007, CAWS data showed that, about 2 hours 47 minutes into the flight, both fuel boost pumps began cycling simultaneously for about 14 minutes. The left fuel boost pump was then on continuously, and the right fuel boost pump was off. The right fuel boost pump resumed cycling about 4 minutes later, and the left fuel boost pump resumed cycling about 11 minutes afterward. About 3 hours 19 minutes into the flight, the left fuel boost pump was on continuously while the right fuel boost pump continued cycling. About 3 hours 27 minutes into the flight, the right fuel boost pump was off, and the left fuel boost pump was on continuously until the final entry for the flight, which was logged about 12 minutes later (at 3:39:16).[64] Table 5 summarizes these data.

Table 5. Central advisory and warning system data for October 2007 flight.

Time in flight	CAWS message	Status
2:47:22	L FUEL PUMP	On—cycling
2:47:22	R FUEL PUMP	On—cycling
3:01:43	L FUEL PUMP	On—continuous
3:01:52	R FUEL PUMP	Off
3:05:38	R FUEL PUMP	On—cycling
3:16:40	L FUEL PUMP	On—cycling
3:19:36	L FUEL PUMP	On—continuous
3:27:27	R FUEL PUMP	Off

In addition, during this investigation, the NTSB learned about a January 2008 event involving a Pilatus PC-12 that diverted and landed uneventfully after the pilot observed both fuel boost pump advisory lights illuminate. Information about this event is discussed in section 1.18.3.

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[63] The autopilot and the yaw damper (rudder trim relief) comprise the PC-12 automatic flight control system.

[64] Maintenance records, service invoices, and airplane flight logs showed that no maintenance actions were performed after this flight in response to the automatic operation of the fuel boost pumps. The next maintenance action, which occurred on December 31, 2007, did not involve the fuel system.

1.16.2.1 Pusher Caution Entries

According to the PC-12 AFM, the annunciation of a PUSHER caution would alert the pilot to a stall warning/stick pusher system malfunction, indicating that the system might be inoperative. As previously stated, during the accident flight, three PUSHER caution entries were logged with a cleared status between flight times 2:23:22 and 2:23:24, even though no PUSHER caution entries had previously been logged with an activated status. Although the NTSB was not able to determine why the three PUSHER caution entries were logged,[65] the NTSB was able to rule out two events that would have resulted in a PUSHER caution being annunciated.

A PUSHER caution would activate only after delays of both 0.3 and 1.0 second, which were the intervals when the caution was annunciated visually and aurally, respectively. The first two PUSHER cautions (both of which were logged at 2:23:22) were consistent with the caution being valid for more than 0.3 second but less than 1.0 second and would have resulted in a brief illumination of the PUSHER light on the CAWS display and no accompanying aural chime in the cockpit. The third PUSHER caution (which was logged at 2:23:24) was consistent with the caution being valid for less than 0.3 second and would have resulted in no illumination of the PUSHER light and no aural chime in the cockpit. Thus, these cautions were evaluated by the CAWS to be valid only for a portion of the total time required for an activated entry to be logged.

According to the CAWS manufacturer, PUSHER caution events could be logged with one of two numeric values depending on the circumstances that precipitated the event. This method allowed the CAWS manufacturer to differentiate among the annunciation modes logged for a PUSHER caution event, including certain component failures of the stick pusher warning system. Other annunciation modes for a PUSHER caution event involved flap asymmetry or an air/ground sensing system fault. If a flap asymmetry event were to occur, the FLAPS caution would illuminate; 10 seconds later, the PUSHER caution would illuminate along with an aural annunciation indicating “flap asymmetry detected, pusher safe mode.” If an air/ground sensing system fault were to occur, an “AIR/GND” warning would be simultaneously annunciated on the CAWS display with the PUSHER caution. Thus, the three PUSHER cautions that were logged during the accident flight were not the result of a flap asymmetry or an air/ground fault because (1) the FLAPS caution and the AIR/GND warning were not logged at any time during the flight and (2) no PUSHER cautions had activated at any time during the flight.

1.16.3 Fuel Consumption Calculations

Pilatus calculated the airplane’s fuel consumption by flight phase (climb, cruise, and descent) for the first and final flight legs on the day of the accident. Pilatus’ estimates were based on engineering data that incorporated the airplane’s actual radar-observed performance. Because

[65] According to the CAWS manufacturer, data are logged to the central advisory computer unit any time that the system evaluates that an event (a warning, caution, or advisory) is valid. A series of delay timers then begin to count down (to ensure that the event is actually valid and not a spurious occurrence), after which the event is logged as “activated,” any associated light on the CAWS display illuminates, and any associated aural annunciation sounds. Additionally, when the event is no longer evaluated to be valid, the event is logged as “cleared.” If the event were to be evaluated as valid but then evaluated not to be valid before all of the associated delays expired, then a “cleared” entry would be logged without a preceding “activated” entry.

no radar data were available for the flight from VCB to OVE, Pilatus used performance charts in the PC-12 AFM to calculate that the airplane consumed about 200 pounds of fuel during that flight leg.

Table 6 shows that Pilatus' estimate of the total fuel consumption for the flight from REI to VCB was 832 pounds. The calculated 56-minute cruise portion of the flight comprised about 7 minutes of flight at FL260 and 49 minutes of flight at FL220.[66] The radar-observed portion of the descent lasted about 22 minutes with an average descent rate of 800 feet per minute. An additional 5 minutes (at the same descent rate) would have been required to descend from the airplane's last radar-observed altitude of 3,900 feet to the near-sea-level elevation of REI, resulting in a 27-minute descent. (It was necessary to determine the portion of the descent that was not supported by radar data to calculate the estimated fuel consumption before the airplane was refueled at VCB.)

Table 6. Fuel consumption estimate for flight from Redlands, California, to Vacaville, California.

Flight phase	Time in hours and minutes	Pounds of fuel burned
Before takeoff	0:00	38
Climb	0:25	206
Cruise	0:56	383
Descent	0:27	204
Total	**1:48**	**832**

Table 7 shows that Pilatus' estimate for the total fuel consumption for the accident flight leg was 979 pounds. The radar-observed portion of the descent lasted about 26 minutes with an average descent rate of about 600 feet per minute from FL250 to 9,100 feet. Radar data were not available for the remaining 3,550 feet in the descent.

Table 7. Fuel consumption estimate for accident flight.

Flight phase	Time in hours and minutes	Pounds of fuel burned
Before takeoff	0:00	38
Climb	0:26	215
Cruise	1:29	581
Descent	0:25	145
Total	**2:20**	**979**

1.16.4 Aircraft Performance Calculations

The CAWS data (in particular, the R FUEL LOW caution that was recorded about 6 minutes before the last CAWS entries for the flight), along with radar data and assumptions about fuel burn, indicated a left-wing-heavy fuel condition just before the accident occurred, with the left wing fuel tank filled to capacity (1,368 pounds) and the right wing fuel tank almost empty (66 pounds).

[66] The airplane reached its first cruise altitude of FL260 at 0809:05 PDT. The airplane remained at this altitude until 0815:43 PDT, at which time the airplane began descending to its second cruise altitude of FL220. At 0904:57 PDT, the airplane began the descent flight phase. The 49 minutes of cruise flight at FL220 included the descent from FL260 to FL220.

The position of the aileron and rudder trim actuators, as recovered in the wreckage, indicated full RWD aileron trim and full ANL rudder trim, which is consistent with a forward sideslip to the right and a left-wing-down rolling moment. A forward right sideslip is a maneuver that the pilot could have used to create drag and increase the descent rate without increasing airspeed, even though the maneuver would have increased the wheel force required to maintain control of the airplane. The rudder input associated with a prolonged rudder pedal input would also result in full ANL rudder trim; the autotrim function would automatically operate the rudder trim system to offload the pedal forces applied by the pilot.

Pilatus calculated that a sideslip with the accident conditions and airspeeds close to the PC-12 stall speed (93 knots) would require 22º (55 percent) of the 40º of available aileron (a left aileron input of 8º and a right aileron input of -14º)[67] with full aileron trim (15º), which would result in a 20-pound control wheel input.[68] These calculations assumed that enough rudder was available to balance the yawing moment (resulting from sideslip) and that the rudder had little effect on the rolling moment.

In addition, Pilatus found that, with the sideslip maneuver, static conditions, and straight and level flight, an airplane with a fuel imbalance of about 1,300 pounds would have been controllable to an airspeed of about 90 knots with about one-half of the available aileron. Pilatus' calculations did not consider the airplane dynamics (for example, yaw and roll rate) associated with landing or the possibility that the pilot was performing a go-around maneuver at low speed at the time of the maximum fuel imbalance.[69]

1.17 Organizational and Management Information

1.17.1 Eagle Cap Leasing

The airplane was registered to Eagle Cap Leasing of Enterprise, Oregon, which was incorporated in March 1992. At the time of the accident, the airplane had three owners. During the month preceding the accident, the airplane was based at REI. (The airplane had previously been based at San Bernardino International Airport, San Bernardino, California.)[70] The pilot was

[67] For the PC-12, down aileron is expressed positively, and up aileron is expressed negatively. Maximum down aileron is 10º, and maximum up aileron is -30º.

[68] Title 14 CFR 23.143, "Controllability and Maneuverability, General," states that the maximum pilot force applied temporarily to the control wheel for roll control is 50 pounds with two hands and 25 pounds with one hand.

[69] Information provided by witnesses was consistent with the pilot performing a go-around maneuver. As previously stated in section 1.1, several witnesses saw the airplane approaching runway 33 but stated that the airplane appeared at a higher altitude than most airplanes that land at the airport. The witnesses also stated that the airplane then flew northwest away from the runway and entered a sharp left turn. Another witness, who saw the airplane break out of a cloud layer several miles south-southwest of the airport, stated that the airplane appeared to fly directly toward the end of the runway but seemed to be at too high of an altitude to complete the landing.

[70] Fueling records from San Bernardino Fixed-Base Operator Services showed that the accident airplane was fueled 40 times between October 2007 and January 2009. The airplane was fueled 33 of those times by a truck carrying fuel that was premixed with a FSII and 7 of those times by a truck carrying fuel that was not premixed with a FSII. During August 2009 and December 2010 interviews, the fuel manager stated that the pilot always requested a FSII when ordering fuel and that a FSII was injected during the fueling process when the truck that was not premixed with this additive was dispatched.

an independent contractor for Eagle Cap Leasing and was the sole pilot of the airplane. Eagle Cap Leasing did not own any other aircraft.

1.17.2 Pilatus Aircraft

According to its website, Pilatus Aircraft was established in 1939. Pilatus' headquarters office is located in Stans, Switzerland, and the company has three independent subsidiaries. One of these subsidiaries is Pilatus Business Aircraft, which is located in Broomfield, Colorado. (The other subsidiaries are located in Adelaide, Australia, and Altenrhein, Switzerland.) Pilatus Business Aircraft, which was established in 1996, is responsible for finishing PC-12 aircraft (which come off the production line in Stans) to customer specifications and coordinating PC-12 servicing activities in North and South America.

1.18 Additional Information

1.18.1 Federal Aviation Administration Policies

1.18.1.1 Safety Belt Regulations

In August 1971, the FAA amended its previous safety belt regulations by adding 14 CFR 91.14, "Fastening of Seat Belts," to its general operating and flight rules to clarify the agency's position on the use of safety belts. Paragraph (a)(2) of the regulation stated the following:

> During the takeoff and landing of U.S. registered civil aircraft…each person on board that aircraft must occupy a seat or berth with a safety belt properly secured around him [or her]. However, a person who has not reached his [or her] second birthday may be held by an adult who is occupying a seat or berth.

The preamble to the rulemaking specified, "it is not intended that separate seats nor separate safety belts be required for operations conducted under Part 91."[71] The intent of the regulation[72] was further supported in June 1990 when the FAA issued legal interpretation 1990-14, which stated the following:

> As long as approved safety belts are carried aboard the aircraft for all occupants, and the structural strength requirements for the seats are not exceeded, the seating of two persons whose combined weights does not exceed 170 pounds under one safety belt where the belt can be properly secured around both persons would not be a violation of the regulations for an operation under Part 91.

[71] 36 *Federal Register* 127 (July 1, 1971).

[72] In December 1985, 14 CFR 91.14(a)(2) became paragraph (a)(3), which also included the following reference to shoulder harnesses: "each person on board [a U.S.-registered civil] aircraft must occupy a seat or berth with a safety belt and shoulder harness, if installed, properly secured about him [or her]."

In August 1990, the FAA revised Part 91, and section 91.14 was redesignated as 14 CFR 91.107, "Use of Safety Belts, Shoulder Harnesses, and Child Restraint Systems." Section 91.107(a)(3) stated that each person on board a U.S.-registered civil aircraft "must occupy an approved seat or berth with a safety belt and, if installed, shoulder harness, properly secured about him or her during movement on the surface, takeoff, and landing."

After the BTM accident, the NTSB asked the FAA for clarification about the intent of 14 CFR 91.107 regarding occupant seats and occupant restraints. In January 2010 correspondence to the NTSB, the FAA stated that, according to section 91.107, multiple (two or more) occupants are allowed to share one seat and one restraint system as long as "the seat usage conformed with the limitations contained in the approved portion of the Airplane Flight Manual" and "the belt was approved and rated for such use."

Further, 14 CFR 91.107(a)(3)(i) continued to permit the practice of allowing a child less than 2 years of age to be held on the lap of an adult.[73] As previously stated, one of the child passengers involved in the BTM accident was 1 year old. In April 2010 correspondence to the NTSB, the FAA stated that this lap child would not have been included in the PC-12 AFM's limitation on the number of occupants[74] because a child who has not reached his or her second birthday is considered to be "part of the adult occupant" rather than a separate occupant.

In addition, 14 CFR 91.107(a)(3)(iii) included provisions permitting approved child restraint systems aboard aircraft. In October 1992, the FAA revised the regulation to broaden the categories of child restraint systems that were allowed to be used on aircraft. In the preamble to the rulemaking, the FAA stated, "using these restraints in an aircraft will provide a level of safety greater than that which would be provided if the young children were held in the arms of adults or if safety belts alone were used."[75]

1.18.1.2 Fuel Anti-Icing Additive Advisory Information

On January 18, 1972, the FAA issued Advisory Circular (AC) 20-29B, "Use of Aircraft Fuel Anti-Icing Additives," which provided information about two approved anti-icing additives that were used to ensure continuous fuel flow during conditions in which ice could occur in turbine aircraft fuel systems.[76] The AC explained that a fuel anti-icing additive was needed because jet fuel, by nature, contains small amounts of water, and the water could turn to

[73] Specifically, this paragraph stated that a person who has not reached his or her second birthday could "be held by an adult who is occupying an approved seat or berth, provided that the person being held…does not occupy or use any restraining device."

[74] As stated in section 1.6, the PC-12 AFM limited the number of occupants (for a corporate commuter configuration) to nine passengers plus pilot(s).

[75] 57 *Federal Register* 42664 (September 15, 1992).

[76] One of the anti-icing additives mentioned in the AC, Military Specification MIL-I-27686, is one of the two anti-icing additives included in the PC-12 AFM. Before 1994, Prist (the commonly known trade name for a FSII) was manufactured according to this specification. Prist now meets Military Specification MIL-DTL-85470, which is the other anti-icing additive included in the AFM.

accumulated ice and clog fuel filters. The use of the additives mentioned in the AC would ensure compliance with 14 CFR 25.997, "Fuel Strainer or Filter," paragraph (b).[77]

For aircraft requiring an anti-icing additive, the AC stated that FAA-approved AFMs should indicate the following information: (1) the minimum concentration of the aircraft fuel anti-icing additive in a loaded fuel tank should be at least 0.035 percent by volume, (2) the minimum concentration of the additive in the fuel with which the aircraft is to be refueled should be at least 0.06 percent by volume, and (3) the maximum concentration of the additive that could be used in fuel was 0.15 percent by volume. (The PC-12 AFM indicated that the anti-icing additive concentration must be between 0.06 and 0.15 percent by volume and cautioned that the correct mix of anti-icing additive with the fuel was important.)[78] In addition, the AC stated that the aircraft should be placarded near the fuel filler cover to show that fuel to be used must contain an anti-icing additive within the minimum and maximum allowed concentrations.

1.18.1.3 Fuel System Icing Advisory Information

On October 22, 1981, the FAA issued AC 20-113, "Pilot Precautions and Procedures to Be Taken in Preventing Aircraft Reciprocating Engine Induction System and Fuel System Icing Problems." The AC provided information about aircraft engine induction system icing in reciprocating (piston-driven) aircraft engines and the use of fuel additives to reduce the hazards of operating with water and ice in aircraft fuel systems.[79]

According to AC 20-113, water in aircraft fuel that freezes and forms ice crystals can block fuel screens, strainers, and filters. The use of anti-icing additives for some piston engine-powered aircraft had been approved to prevent problems caused by water and ice in aviation fuel. Laboratory and flight testing demonstrated that the use of an anti-icing additive at a maximum concentration of 0.15 percent by volume could substantially inhibit fuel system icing under most operating conditions. The AC cautioned that the concentration of the anti-icing additive in the fuel was critical because a marked deterioration in its effectiveness could result from too little or too much additive. The AC concluded that fuel anti-icing additives are beneficial in preventing fuel system icing when they are properly blended in the fuel systems of piston engine-powered aircraft.

As stated in section 1.6, the accident airplane was equipped with a turbine engine and not a reciprocating engine. AC 20-113 contained no guidance on fuel system icing prevention for operators of turbine engine-powered aircraft. Section 2.4 discusses the need for such guidance.

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[77] Title 14 CFR 25.997(b), which was effective on May 8, 1970, stated the following: "unless there are means in the fuel system to prevent the accumulation of ice on the filter, there must be means to automatically maintain the fuel flow if ice-clogging of the filter occurs." Title 14 CFR 23.997(d), which was effective on September 14, 1969, stated the same requirement but for normal- and commuter-category aircraft with turbine engine fuel systems. Both regulations were subsequently amended and became part of two new regulations: 14 CFR 23.951(c), which is discussed in section 1.6.5.1, and 14 CFR 25.951(c), which has identical requirements to section 23.951(c) but applies to transport-category airplanes. Both of the new regulations became effective on October 31, 1974.

[78] According to Pilatus, concentrations less than 0.06 percent might not prevent ice formation in the fuel system, and concentrations greater than 0.15 percent could damage the primer and sealants in the fuel tanks and the sealants in fuel system and engine components.

[79] The AC stated that improved pilot awareness, attention, and adherence to recommended procedures should reduce the number of accidents involving engine induction and fuel system icing.

1.18.2 Previous Related Safety Recommendations

1.18.2.1 Occupant Restraints

On August 11, 2010, the NTSB issued Safety Recommendations A-10-121 and -122 because of its concern that, if the FAA were to continue allowing multiple occupants aboard airplanes operating under Part 91 to share a single seat position[80] and a single restraint system, then those occupants would not benefit from the improved protection provided by the crashworthiness requirements of Part 23.[81] Also, the NTSB recognized that, if this accident had been less severe and the impact had been survivable, any unrestrained occupants or occupants sharing a single restraint system would have been at a much greater risk of injury or death.[82] The recommendations asked the FAA to do the following:[83]

> Amend 14 *Code of Federal Regulations* Part 91 to require separate seats and restraints for every occupant. (A-10-121)

> Amend 14 *Code of Federal Regulations* Part 91 to require each person who is less than 2 years of age to be restrained in a separate seat position by an appropriate child restraint system during takeoff, landing, and turbulence. (A-10-122)

On October 14, 2010, the FAA stated that it was reviewing these recommendations to determine whether a revision of the current interpretation of section 91.107 would be appropriate. The FAA also stated that it was reviewing the studies cited by the NTSB in its letter to determine the most appropriate action regarding Safety Recommendation A-10-122. The FAA indicated that it would keep the NTSB informed about the FAA's progress on both safety

[80] The NTSB recognizes that some airplanes operating under Part 91 are configured with seats that have more than one seating position. For example, the Bombardier Challenger CL-600 involved in the February 2, 2005, accident in Teterboro, New Jersey, was configured with a divan that had three separate seating positions.

[81] Title 14 CFR 23.562, "Emergency Landing Dynamic Conditions," paragraph (a)(1), stated that each seat and restraint system for use in an airplane must be designed to protect each occupant during an emergency landing when "proper use is made of seats, safety belts, and shoulder harnesses provided for in the design." Section 23.562 also addressed dynamic testing with an anthropomorphic test dummy (ATD) and required, among other things, that the shoulder harness remain on the ATD's shoulder and the safety belt remain on the ATD's pelvis during the impact. Neither of these conditions could be met with multiple occupants sharing a single seat and restraint system, as allowed by 14 CFR 91.107. The NTSB recognizes that many airplanes operating under Part 91 were certified before the time that the improved crashworthiness standards were adopted but believes that occupants of those airplanes would also benefit from single-occupant use of seats and restraint systems.

[82] On December 9, 2010, the NTSB held a public forum to promote child passenger safety. The primary purposes of the forum were to (1) improve child safety in airplanes and automobiles through education and advocacy aimed toward the caregivers of children and the transportation industry and (2) identify effective strategies to increase child seat and seatbelt user rates. For information from the forum, see <http://www.ntsb.gov/events/symp-child-passenger-2010/symp-child-passenger.htm>.

[83] In its letter transmitting Safety Recommendations A-10-121 and -122, the NTSB stated that, although 14 CFR 121.311, "Seats, Safety Belts, and Shoulder Harnesses," and 135.128, "Use of Safety Belts and Child Restraint Systems," require separate seats and restraints for each person, the regulations allow children who have not reached their second birthday to be held on an adult's lap (similar to 14 CFR 91.107). As a result, the NTSB issued Safety Recommendation A-10-123, which asked the FAA to "amend 14 *Code of Federal Regulations* Parts 121 and 135 to require each person who is less than 2 years of age to be restrained in a separate seat position by an appropriate child restraint system during takeoff, landing, and turbulence." For more information, see <http://www.ntsb.gov/Recs/letters/2010/A-10-121-123.pdf>. On January 31, 2011, Safety Recommendation A-10-123 was classified "Open—Unacceptable Response."

recommendations. On January 31, 2011, the NTSB classified Safety Recommendations A-10-121 and -122 “Open—Acceptable Response” pending completion of the recommended actions.

On June 23, 2011, the FAA published, in the *Federal Register*, a Clarification of Prior Interpretations of the Seat Belt and Seating Requirements for General Aviation Flights. The FAA’s proposal continues to allow the shared use of a seat and restraint system and relies on the “good judgment of the pilot” to determine the proper method of restraint for children during operations conducted under Part 91. The NTSB’s response to the FAA’s proposal is presented in section 2.5.

1.18.2.2 Pilot Receipt of Weather Information

On March 18, 2010, the NTSB issued Safety Recommendation A-10-42 as a result of the BTM accident and the October 2009 Northwest Airlines flight 188 incident,[84] which raised concerns about ATC procedures for documenting communications with pilots.[85] Safety Recommendation A-10-42 asked the FAA to do the following:

> Establish and implement standard procedures to document and share control information, such as frequency changes, contact with pilots, and the confirmation of the receipt of weather information, at air traffic control facilities that do not currently have such a procedure. These procedures should provide visual communication of at least the control information that would be communicated by the marking and posting of paper flight-progress strips described in Federal Aviation Administration Order 7110.65, “Air Traffic Control.”

On June 7, 2010, the FAA stated that its Air Traffic Organization office was forming a working group of subject matter experts to assess Safety Recommendation A-10-42. On November 29, 2010, the NTSB responded that it looked forward to reviewing the results of the group’s work and classified the recommendation “Open—Acceptable Response.”

On February 16, 2011, the NTSB again corresponded with the FAA about Safety Recommendation A-10-42 because, since the time of its November 2010 letter, the NTSB learned that the FAA planned to replace the fully automated Host computer system currently used at high-altitude en route centers with the en route automation modernization (ERAM) system. The NTSB indicated that, before the implementation of the Host computer system, the transfer of aircraft information between air traffic controllers occurred through the use of flight

[84] The NTSB found that the pilots of Northwest Airlines flight 188 did not communicate with ATC for about 1 hour 17 minutes because they were distracted by conversations and activities that were unrelated to the operation of the flight. During that time, the airplane flew past its intended destination. The NTSB also found that two sector controllers within the Denver ARTCC airspace did not document, and were not required to document, flight progress strip information indicating that the flight crew had not yet established contact. Additional information about this incident, NTSB case number DCA10IA001, is available at <http://www.ntsb.gov/aviationquery/index.aspx>.

[85] As stated in section 1.10.2, FAA Order 7110.65, paragraph 4-7-10, requires ATC to ensure that pilots have received weather and NOTAM information for the destination airport. However, neither this order nor FAA Order 7210.3 requires controllers to document that a pilot has been issued or has reported receiving weather and NOTAM information for the destination airport.

progress strips but that, when the Host system was deployed, some of the information that had been transferred using flight progress strips was no longer being transferred. The NTSB advised the FAA that a fully acceptable response to this safety recommendation must address how both future systems, such as ERAM, and current systems, such as Host, would prevent the loss of important information when aircraft are transferred between air traffic controllers.

1.18.2.3 Flight Recorder Systems

On February 9, 2009, the NTSB issued Safety Recommendations A-09-10 and -11 as a result of its ongoing concern about the need for flight recorder systems for smaller aircraft not equipped with a CVR or an FDR.[86] These safety recommendations asked the FAA to do the following:[87]

> Require all existing turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with a 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, 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 to be specified in European Organization for Civil Aviation Equipment document ED-155, "Minimum Operational Performance Specification for Lightweight Flight Recorder Systems," when the document is finalized and issued. (A-09-10)

> Require all existing turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with a flight data 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 (if a cockpit voice recorder is not installed), 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 to be specified in European Organization for Civil Aviation Equipment document ED-155, "Minimum Operational Performance Specification for Lightweight Flight Recorder Systems," when the document is finalized and issued. (A-09-11)

[86] The NTSB also issued Safety Recommendation A-09-9 to the FAA to address the installation of a crash-resistant flight recorder system on all newly manufactured turbine-powered, nonexperimental, nonrestricted-category aircraft that are not equipped with an FDR and are operating under 14 CFR Parts 91, 121, or 135. The recommendation was classified "Open—Unacceptable Response" on December 23, 2010.

[87] Safety Recommendation A-09-10 superseded Safety Recommendation A-03-64, which asked the FAA to "require all turbine-powered, nonexperimental, nonrestricted-category aircraft that are manufactured prior to January 1, 2007, that are not equipped with a cockpit voice recorder, and that are operating under 14 *Code of Federal Regulations* Parts 91, 135, and 121 to be retrofitted with a crash-protected image recording system by January 1, 2007." Safety Recommendation A-09-11 superseded Safety Recommendation A-03-65, which asked the FAA to "require all turbine-powered, nonexperimental, nonrestricted-category aircraft that are manufactured prior to January 1, 2007, that are not equipped with a flight data recorder, and that are operating under 14 *Code of Federal Regulations* Parts 135 and 121 or that are being used full-time or part-time for commercial or corporate purposes under Part 91 to be retrofitted with a crash-protected image recording system by January 1, 2010." Both recommendations were classified "Closed—Unacceptable Action/Superseded" on February 9, 2009.

On May 25, 2010, the FAA stated that it decided to develop and publish a technical standard order (TSO) for a lightweight recording system that included certain requirements of European Organization for Civil Aviation Equipment (EUROCAE) document ED-155, which was published in August 2009. The FAA further stated that it would not mandate these recording systems on all turbine-powered, nonexperimental, nonrestricted-category aircraft but that it would consider mandating “ED-155-like recording systems” on certain aircraft based on specific types of operation. On November 15, 2010, the FAA published TSO-C197, “Information Collection and Monitoring Systems,” which addressed lightweight recording systems.

On December 23, 2010, the NTSB stated that retrieving valuable recorded data from all turbine-powered aircraft during an accident investigation was essential regardless of the aircraft’s type of operation or the number of engines, pilots, or passenger seats. The NTSB pointed out that data recording systems, as well as audio and image recording systems, were available and affordable for smaller aircraft. The NTSB urged the FAA to mandate approved lightweight recording systems for all turbine-powered aircraft. The NTSB classified Safety Recommendations A-09-10 and -11 “Open—Unacceptable Response.”

On February 15, 2011, the FAA stated that TSO-C197 included certain requirements from EUROCAE document ED-155. The FAA believed that the TSO standardized the design and production certification requirements for equipment manufacturers to streamline aircraft installation and integration. The FAA indicated that it did not intend to mandate additional recording systems on all turbine-powered, nonexperimental, nonrestricted-category aircraft.

On May 18, 2011, the NTSB cited several recent accident investigations that would have benefited from flight recorder system data, including the BTM accident. The NTSB again urged the FAA to reconsider its position not to mandate flight recorder systems on all turbine-powered, nonexperimental, nonrestricted-category aircraft. Safety Recommendations A-09-10 and -11 remained classified “Open—Unacceptable Response” pending the FAA’s completion of the recommended actions in a timely manner.

1.18.3 Previous Related Event

On January 30, 2008, a Pilatus PC-12, N666M, was en route from Riverside Municipal Airport, Riverside, California, to Great Falls International Airport, Great Falls, Montana, when the pilot noted an anomaly about 3 hours into the flight. (The NTSB learned of this event from the owner of the accident airplane who organized the trip during which the accident occurred. The pilot of N666M was not the accident pilot.) According to an interview with N666M’s pilot, which occurred in November 2009 (8 months after the BTM accident), he observed both fuel boost pump advisory lights illuminate steadily and heard a noise that sounded as if the boost pumps were “struggling.” At the time, the airplane was operating between FL230 and FL250 and with an outside air temperature of about -30° C.

Because of the pilot’s concern, he descended the airplane to FL190 and began to consider diverting to another airport. The pilot stated that he did not declare an emergency because two nearby airports (with maintenance facilities) were available but that he would have been more concerned about the situation if no airports were available within 100 miles. The pilot identified Idaho Falls Regional Airport, Idaho Falls, Idaho, as the diversion airport because it had better prevailing weather conditions, and he began to maneuver to the airport about 10 minutes after the event began. The airplane landed uneventfully about 15 minutes later.

After landing, the pilot took a fuel sample and noticed that it appeared “a little abnormal” and “slightly opaque or cloudy” in appearance. The pilot was concerned that the fuel in the airplane did not contain a FSII. He called the FBO that had last serviced the airplane with fuel and was told that a FSII had been used. (Fuel records were not available to verify this information or determine the amount of fuel that had been added to the airplane during servicing.)

The owner of N666M, who was aboard the airplane during the flight, was also interviewed in November 2009 about the event. He stated that the pilot chose to divert and land as a precaution. The airplane owner stated that the pilot suspected that the reason for the operation of the fuel boost pumps was ice in the fuel. The owner indicated that the fuel sample secured by the pilot contained floating ice crystals. The owner also recalled looking at the fuel sample about 45 minutes later, after it had warmed, and noticing that the fuel appeared “crystal clear” with no evidence of ice or other contamination present.

The pilot placed the airplane in a heated hanger for the night and serviced it with fuel that contained a FSII. The pilot reported that the airplane operated without any abnormalities the next morning and that he did not encounter any further difficulties with the airplane. In addition, the pilot stated that the fuel filter bypass indicator was not extended during the preflight inspection that followed the event and that he did not notice any fuel imbalance, engine problem, or illumination of the low fuel pressure caution light during the event.

The owner of N666M gave the NTSB permission to download the CAWS data from the airplane. The data, which were downloaded in December 2009, showed that, about 28 minutes into the flight, the right fuel boost pump was on continuously for 3 minutes 42 seconds. This time period was consistent with automatic lateral fuel balancing. The data also showed that, about 3 hours into the flight, both fuel boost pumps began cycling simultaneously for 9 seconds. About 20 seconds later, a fuel pressure caution was cleared (even though no previous activation of a fuel pressure caution had been logged), and both fuel boost pumps continued cycling. About 3 hours 11 minutes into the flight, the left fuel boost pump was on continuously, and the right fuel boost pump was off. The fuel boost pumps resumed cycling about 5 1/2 minutes later. About 3 hours 24 minutes into the flight, the left fuel boost pump was on continuously, and the right fuel boost pump was off. About 5 minutes later, both fuel boost pumps resumed cycling for about 3 minutes. Afterward, both fuel boost pumps were off. These data are presented in table 8.

Table 8. Central advisory and warning system data for N666M.

Time in flight	CAWS message	Status
0:28:26	R FUEL PUMP	On—continuous
0:32:08	R FUEL PUMP	Off
2:59:50	L FUEL PUMP	On—cycling
2:59:50	R FUEL PUMP	On—cycling
3:00:19	FUEL PRESS	Off—no FUEL PRESS activation logged
3:11:29	L FUEL PUMP	On—continuous
3:11:38	R FUEL PUMP	Off
3:17:04	L FUEL PUMP	On—cycling

Time in flight	CAWS message	Status
3:17:04	R FUEL PUMP	On—cycling
3:24:34	L FUEL PUMP	On—continuous
3:24:43	R FUEL PUMP	Off
3:29:51	L FUEL PUMP	On—cycling
3:29:51	R FUEL PUMP	On—cycling
3:32:56	L FUEL PUMP	Off
3:32:57	R FUEL PUMP	Off

1.18.4 Aviation Safety Reporting System Reports

The National Aeronautics and Space Administration's (NASA) aviation safety reporting system (ASRS) is a national repository for reports regarding aviation safety-related issues and events. The NTSB's search of the ASRS database found three deidentified reports related to the circumstances of the BTM accident.[88]

The first report was provided by a Cessna CE-560 pilot who indicated that, during cruise flight at FL370, the right fuel filter bypass light illuminated. The pilot further reported that the checklist for this indication showed that the airplane should land as soon as practical. The pilot indicated that, after discussing diversion airport options with the first officer, he observed the left fuel filter bypass light illuminate, and he and the first officer decided to declare an emergency and land at the first available airport. The airplane landed without further incident. The pilot believed that the reported event occurred because a fueler at an FBO had not injected a FSII into the fuel, as required for the CE-560. The pilot reported that, because of other flight-related tasks, he was unable to monitor the fueling. The pilot also believed that, to prevent the reported event from recurring, pilots should "make every effort to monitor fueling. If there are other items to attend to…either delay fueling or attend to those items later."

The second report was provided by the pilot of a Learjet 35 that was en route from Memphis, Tennessee, to Spokane, Washington, with a planned fuel stop in Boise, Idaho. The pilot reported that, about 175 miles southeast of Boise, the left fuel filter light illuminated, indicating that fuel was bypassing the fuel filter. The pilot suspected ice in the fuel filter and turned on the standby pumps. Afterward, the left engine flamed out. The pilot reported that he contacted ATC to request a lower altitude and a divert to Idaho Falls, which were authorized. (The pilot did not declare an emergency or inform the controller of the engine flameout.) At the time of the reported event, the airplane had been operating at FL430 and with an outside air temperature of -72º C. During the descent to Idaho Falls, the fuel filter light extinguished, and the left engine was restarted and then operated normally. The airplane landed uneventfully. The pilot reported that, when the airplane was refueled, he ensured that a FSII had been added to the fuel. When the airplane returned to Memphis after the trip, the company maintenance chief found a problem at the facility where the airplane was fueled before the trip. A supply line incorporating a FSII into the jet fuel was kinked, so the additive had not been added to the fuel.

The third report was provided by a pilot of a Cessna Citation V who indicated that he had requested a full load of fuel for his aircraft. The pilot stated that he would normally observe a

[88] Because ASRS reports are submitted voluntarily, the existence of reports concerning a specific topic in the ASRS database cannot be used to infer the prevalence of that problem within the National Airspace System.

fueling but that he had previous favorable experiences with the FBO and trusted that the airplane would be fueled properly. According to the pilot, he emphasized that a FSII needed to be added to the fuel and, before departure, confirmed with the FBO that a FSII had been added. During flight, both the left and the right fuel filter bypass lights illuminated. The pilot stated that, because these lights indicated fuel contamination or icing and possibly an impending engine flameout, he made an emergency descent and landed without further incident. The pilot reported that he refueled the aircraft at the diversion airport with fuel containing a FSII. Also, he indicated that the fuel filter bypass lights extinguished while the airplane was on the ground. The pilot stated that he reported the event to the FBO and that personnel told him that there might have been a problem with the FSII injector. The pilot did not know if that was the case or if the reported event was actually caused by “forgetfulness” on the part of the fueler.

The Cessna Citation pilot included four recommended actions in his ASRS report: premix a FSII in the fuel; develop a kit to allow pilots to verify, during preflight inspections, whether a FSII is present in fuel; have FBOs frequently test their fuel (for the presence of a FSII); and promote awareness among fuel service personnel about the required need for a FSII on certain aircraft.[89] In addition, the pilot indicated that, if the flight had been operated at a lower altitude in warmer air, then he would not have known about the discrepancy.

1.19 Useful or Effective Investigation Techniques

As stated in section 1.11, the airplane was not equipped and was not required to be equipped with a CVR or an FDR. Information that was critical to this investigation was discovered by extracting data from the nonvolatile memory stored in the CAWS central advisory control unit.[90] The data showed the abnormal number of fuel boost pump activations on the accident and two other flights and led to the fuel boost pump testing discussed in section 1.16.1.

The download of the nonvolatile memory data was initially attempted at the laboratory of the CAWS manufacturer—Aircraft Electronics Engineering GmbH of Seefeld/Droessling, Germany. The components within the airplane’s CAWS central advisory control unit that maintained the nonvolatile memory (contained on flash memory chips) were located on a sub-board. The sub-board was intact but had impact damage, and many of the sub-board’s input and output pins were bent. The pins that were necessary for accessing and downloading data were straightened, and the pins were connected to a power supply that limited electrical current flow. Continuity testing found that the pins had shorted, so a download of the data from the sub-board was not possible.

[89] Regarding the pilot’s recommended actions, the NTSB notes that not all aircraft require a FSII. The NTSB also notes that portable test kits are currently available to pilots and operators to determine the volume, or percent, of a FSII in jet fuel before a flight. This determination is made using the testing device, a small quantity of fuel from the aircraft’s fuel tanks, and a sample of water (to ensure that the FSII would prevent the formation of ice crystals). In addition, the NTSB is proposing a recommendation in section 2.3 that would help promote awareness about the need for a FSII on aircraft that require the additive.

[90] The airplane’s attitude and heading reference system was also identified as a possible source of nonvolatile memory. The content of the memory chips from one of the system’s units was downloaded successfully, and the data showed that the unit had accumulated about 2,007 total hours of operation with 90 faults logged during that time. No faults were logged for any flights on the day of the accident; the most recent fault was logged when the unit had accumulated about 1,951 hours.

The flash memory chips from the airplane’s sub-board were then taken to the laboratory of the Federal Bureau of Aircraft Accident Investigation of Braunschweig, Germany. The memory chips were placed in a multipurpose data extraction device, and the data were successfully downloaded. To decode the downloaded data, the CAWS manufacturer modified its existing computer program so that the data could be translated into plain text. The translated data included unique log entry numbers; unique flight numbers (as indicated by each weight-on-wheels event); the date and the time; a text description of the warning, caution, or advisory that was logged; and the status of the annunciation (on or off).

The recovery of nonvolatile memory data has proven to be extremely valuable during other accident investigations involving general aviation aircraft.[91] The cockpit instrumentation installed on some of these aircraft recorded data similar to those that are stored on an FDR. The data that were recovered provided a time history of the route of flight, the attitude of the aircraft, and other operational and aircraft systems information. These data helped investigators focus on the circumstances that led to the accident.

[91] For examples of such accident investigations, see NTSB case numbers CHI06FA245 and NYC08FA138 on the NTSB’s website at <http://www.ntsb.gov/aviationquery/index.aspx>.

2. Analysis

2.1 General

The investigation found that the pilot was properly certificated and qualified in accordance with applicable Federal regulations. The investigation also found no evidence indicating any preexisting medical or behavioral condition that might have adversely affected the pilot's performance on the day of the accident. Further, the investigation found that the airplane was properly certified, equipped, and maintained in accordance with Federal regulations and that the recovered components showed no evidence of any preimpact structural, engine, or system failures.

Weather was not a factor in the accident. BTM was reporting VMC at the time of the accident, and the pilot reported that he had the airport in sight 11 miles from the airport. Pilot reports indicated light to moderate icing conditions en route to and in the area of the accident, but these reports also indicated that the icing conditions were normal for the area and could be controlled by airplane deice boots.[92]

This analysis discusses the accident sequence, including fuel boost pump activity, the airplane's descent into the BTM area and ground impact, and the pilot's decision-making before and during the accident flight. The analysis also discusses fuel system limitations, requirements for fuel filler placards, and guidance on fuel system icing prevention, crash protection for airplane occupants, and flight recorder systems for general aviation aircraft.

2.2 Accident Sequence

2.2.1 Overview

The Pilatus PC-12 AFM requires that a FSII be added to jet fuel for all operations conducted in outside (ambient) air temperatures below 0º C to prevent ice particles from forming in fuel. The three flight legs on the day of the accident (REI to VCB, VCB to OVE, and OVE to BZN with a divert to BTM) were all operated in temperatures below 0º C.

The accident pilot began work as an independent contractor for Eagle Cap Leasing (the operator of the accident airplane) in November 2002 and was the sole pilot of the airplane. Before his employment with Eagle Cap Leasing, the pilot flew the PC-12 for Native American Air Ambulance, but the former director of operations for the company recalled that a FSII was not used for the company's flights. However, because the pilot had been employed with Eagle Cap Leasing for more than 6 years at the time of the accident, he should have been routinely using a FSII when servicing the airplane with fuel. On a standard day, the temperature is 0° C at 7,500 feet, so most of the flights conducted by the pilot for Eagle Cap Leasing (according to the airplane's flight log) would have required the use of a FSII. Fueling records between

[92] CAWS data showed that the accident airplane's deice system was activated 2 hours 3 minutes into the flight (about 1413) and remained activated through the time of the last CAWS entry logged for the flight (about 1433).

October 2007 and January 2009 indicated that the pilot requested a FSII when fueling the airplane at its previous operating base, but fueling records from February and March 2009 showed that a FSII was not added during the four times that the airplane was fueled at its current operating base (REI).

Analysis of data downloaded from the airplane's CAWS showed that, during the flight from REI to VCB and the accident flight leg, a low fuel pressure state existed, which necessitated the automatic operation of the left and right fuel boost pumps to provide the required fuel pressure to the engine. The flight from REI to VCB concluded uneventfully. However, for the accident flight leg, the low fuel pressure state and a restricted flow of fuel from the left wing tank led to a left-wing-heavy fuel imbalance that exceeded 1,300 pounds, which ultimately resulted in a loss of control as the pilot maneuvered the airplane near the approach end of the runway.

The airplane had been serviced with fuel on the day before the accident at REI and after landing at VCB, but the pilot failed to ensure that a FSII had been added to the fuel, even though he was aware that the flights would be operated at outside air temperatures that required the additive. Analysis of radar data showed that both flights were operating in below-freezing temperatures for almost their entire duration.

In addition, Pilatus' procedures required the pilot to (1) monitor the fuel quantity indicator in the cockpit to ensure fuel symmetry between the left and right fuel tanks during flight, and, in the event that fuel balance was not automatically maintained, (2) manually balance the fuel by turning ON the fuel pump for the fuel tank with the higher quantity, and, if unable to restore balance, (3) land the airplane as soon as practical. During the accident flight, the pilot did not begin to divert until about 20 to 31 minutes after his attempt to manually restore fuel balance was unsuccessful, and he chose BTM even though several closer airports along the airplane's route of flight were available. The pilot had likely downplayed the seriousness of the initial advisories because no adverse outcomes resulted from ignoring the advisories during the flight from REI to VCB and during an October 2007 flight, when a low fuel pressure state existed that also necessitated the automatic operation of the left and right fuel boost pumps to provide the required fuel pressure to the engine (see section 1.16.2).

Because the pilot did not take action to land the airplane as soon as practical after his attempt to manually restore fuel balance was unsuccessful, the fuel imbalance continued to worsen beyond the maximum imbalance limitation, increasing the airplane's left rolling moment as the flight progressed. The accident sequence is further discussed in sections 2.2.2 through 2.2.6.

2.2.2 First Two Flight Legs

The accident airplane had been fueled to its 406.8-gallon (2,736-pound) capacity on the day before the accident with 222 gallons (1,494 pounds) of Jet A fuel. The fuel truck at REI contained fuel that was not premixed with a FSII, but the fuel pump contained provisions for injecting a FSII during fueling. However, the pilot did not request that a FSII be added when the airplane was fueled.

On the day of the accident, the pilot departed REI for VCB as the sole occupant of the flight. According to EIS trend data for the flight, the average outside air temperature was -32º C when the airplane was operating at its cruise altitude.[93] About 1 hour 30 minutes into the flight, while the airplane was descending through an altitude of about 10,000 feet, the left and right fuel boost pumps began cycling (generally on for 10 seconds and off for 1 second). According to the Pilatus PC-12 AFM, the fuel boost pumps operate automatically if a low fuel pressure state exists—which occurs when fuel system pressure drops below 2 psi—and the pump's switch is set to the AUTO position.[94] By design, the CAWS annunciates a low fuel pressure caution when fuel system pressure drops below 2 psi for more than 0.3 second. However, because the CAWS did not log any fuel pressure cautions during the flight, it is likely that at least one of the fuel boost pumps was able to provide adequate pressure to the fuel system (at least 3.5 psi) within 0.3 second of the low fuel pressure condition being sensed.

The fuel boost pumps continued cycling for 15 minutes, even though they were designed to turn off automatically 10 seconds after the fuel system pressure was restored to 3.5 psi. Thus, it is likely that the fuel pressure dropped below 2 psi each time the boost pumps turned off, so the pumps continued cycling to return pressure to 3.5 psi within 0.3 second.

After both fuel boost pumps had cycled for 15 minutes, the left fuel boost pump was on continuously, and the right fuel boost pump was off. This change in status occurred because, as the fuel boost pumps operated to correct the low fuel pressure situation, a left-wing-heavy fuel imbalance of about 70 pounds was created. According to Pilatus, when a fuel imbalance of about 70 pounds (5 percent of each wing's total fuel capacity) occurs, the fuel boost pump in the tank with the higher fuel quantity operates automatically, and the fuel boost pump continues to operate until the fuel levels in both tanks are equalized. Pilatus also stated that a single fuel boost pump operating continuously could simultaneously correct a fuel imbalance and a low fuel pressure state. A fuel imbalance of about 70 pounds is displayed on the EIS fuel quantity indicator (see figure 4) by a two-bar differential between the fuel tanks.

The left fuel boost pump was on continuously until the end of the flight, which occurred about 6 minutes later. The left fuel boost pump was able to maintain the required fuel system pressure during this time without the operation of the right fuel boost pump. Because the left fuel boost pump had not turned off before the end of the flight, it is likely that the fuel balancing system was still automatically rebalancing the fuel load at that time.

When the airplane arrived at VCB, the pilot refueled the airplane at the airport's self-service fueling island with about 128 gallons (861 pounds) of Jet A fuel.[95] At this point, the fuel tanks would most likely have been refilled to their maximum capacity (1,368 pounds each). The fuel dispensed at the VCB self-service fueling island was not premixed with a FSII, and the

[93] EIS trend data recorded between 0823:53 and 0905:05 PDT showed that, when the airplane was operating at FL220, the total air temperature was -24º C. The average outside air temperature, which is corrected for airspeed, was -32º C.

[94] As stated in section 1.6.1, each fuel boost pump is controlled by a two-position (AUTO or ON) switch. The AUTO position is the normal setting, and the fuel boost pumps operate automatically when a pressure switch within the fuel system's air separator detects fuel pressure below 2 psi. With the fuel boost pump switches set to the ON position, the fuel boost pumps operate continuously and independently of the fuel pressure at the time.

[95] The fuel consumption estimate for the flight from REI to VCB was 832 pounds.

fuel pump did not contain provisions for injecting a FSII during fueling. No evidence suggested that the pilot had used any other method to add a FSII to the fuel either before or during the fueling.

Surveillance video obtained from VCB showed the pilot performing some parts of the required preflight inspection. However, the video showed no evidence that the pilot had sampled fuel from either of the underwing fuel tank drains or the fuel filter drain. Also, the surveillance video did not show any evidence that the pilot examined the fuel filter bypass indicator to ensure that it was flush with the filter housing assembly. The NTSB concludes that, if the pilot had performed a complete preflight inspection before the flight to OVE, he would have had an opportunity to detect whether ice crystals or water were present in the fuel and determine whether the fuel filter bypass indicator was extended, which could have explained the reason for the fuel boost pump advisories annunciated during the preceding flight.

The pilot and nine passengers boarded the airplane for the flight to OVE, even though the flight plan that the pilot had filed the day before indicated that a total of five people would be on board the airplane at that point. (The number of passengers on board the airplane and the number of seats available to the passengers are discussed in detail in section 2.5.)

EIS flight summary data showed that, during the short flight from VCB to OVE, the airplane operated at a maximum altitude of 6,000 feet, where the outside air temperature was about -4° C. Thus, the airplane was exposed to higher outside air temperatures than those encountered by the airplane during the previous flight leg and the accident flight leg; however, a FSII was still required (per the PC-12 AFM) for the flight from VCB to OVE. The CAWS did not log any fuel boost pump activity for this flight. The fuel consumption estimate for the flight from VCB to OVE was about 200 pounds.

2.2.3 Accident Flight Leg

When the airplane arrived at OVE, four additional passengers boarded the airplane, bringing the total number of airplane occupants to 14 people (the pilot, six adult passengers, and seven child passengers aged 1 to 9 years). The flight plan for this flight leg indicated that a total of nine people would be on board the airplane at this point.

The airplane departed OVE for BZN about 1210 with an estimated 1,268 pounds of fuel in each tank (assuming equal lateral fuel burn during the flight from VCB to OVE). According to CAWS data, about 22 minutes into the flight (about 1232),[96] the right fuel boost pump was on continuously for 3 minutes 45 seconds.[97] This activity was consistent with normal operation of

[96] As stated in section 1.16.2, the flight times recorded by the CAWS central advisory control unit and the times that the airplane was observed by radar were resolved to within 4 1/2 minutes, and all time correlations between the CAWS and local times are estimates.

[97] As stated in section 1.6.1, fuel boost pump activations are delayed by 1 minute to allow the fuel balancing system to determine whether an actual fuel imbalance is occurring rather than fuel movement as a result of turbulence. Thus, CAWS data showed that the fuel balancing system detected the 70-pound imbalance about 1231 and that the right fuel boost pump activated about 1232.

the automatic fuel balancing system to laterally balance the fuel load.[98] At that time, the EIS fuel quantity indicator would have displayed a two-bar differential between the left and the right fuel tanks (with the right tank containing more fuel), indicating a fuel imbalance of 70 pounds and a right-wing-heavy condition. (All references to the bar differential that would have been displayed on the fuel quantity indicator are based on the 1,352-pound usable fuel capacity in each wing fuel tank.) Once the 70-pound imbalance was corrected (at which point the right fuel boost pump would have turned off), the fuel quantity indicator would no longer have shown a difference between the amount of fuel in the left and the right fuel tanks. The CAWS did not log any further fuel boost pump activity for the next 48 minutes of flight.

2.2.3.1 Fuel Boost Pump Activity

About 1 hour 13 minutes into the flight (about 1323), both fuel boost pumps began cycling because of a low fuel pressure state. EIS trend data showed that the airplane was operating at the time at its cruise altitude and with an average outside air temperature of -40º C.[99] Both fuel boost pumps continued cycling during the next 4 1/2 minutes. No CAWS low fuel pressure cautions were logged during the flight, indicating that the low fuel pressure state was alleviated by the operation of one or both fuel boost pumps.

About 1 hour 18 minutes into the flight (about 1328), the left fuel boost pump was on continuously, and the right fuel boost pump was off. The continuous operation of the left fuel boost pump indicated that the pump had been commanded to operate by the fuel balancing system to automatically correct a fuel imbalance of at least 70 pounds while the pump also operated to maintain adequate fuel system pressure.[100] The fuel imbalance, which had developed between the left and the right fuel tanks (with the left tank containing more fuel than the right tank), would have been displayed by a two-bar differential on the fuel quantity indicator. This imbalance was likely created because the right fuel boost pump had delivered more fuel to the engine than the left fuel boost pump had delivered (likely as a result of a restricted flow of fuel from the left wing tank) during the time that both fuel boost pumps were simultaneously cycling. During the next 3 minutes, the operation of the left fuel boost pump had likely reduced the left-wing-heavy fuel imbalance to within about 15 pounds.

About 1331, the right fuel boost pump resumed cycling. The operation of the right fuel boost pump indicated that (1) the fuel pressure output of the left-side fuel system had degraded to less than 2 psi, even with the left fuel boost pump on continuously; (2) the required fuel system pressure could no longer be maintained through the operation of the left fuel boost pump; and

[98] The 3-minute 45-second duration of this activation was consistent with the average duration of 29 other automatic fuel boost pump activations that were downloaded from the accident airplane's CAWS. The duration of the activation was also consistent with the 3-minute 42-second duration of the automatic fuel boost pump activation that was downloaded from the CAWS installed on N666M. All of these activations were considered normal lateral fuel balancing events because balancing 70 pounds of fuel within about 4 minutes is an expected behavior of the automatic fuel balancing system.

[99] EIS trend data recorded between 1237:03 and 1405:24 showed that the airplane was operating at FL250 and with a total air temperature of -32º C. The average outside air temperature (corrected for airspeed) was -40º C.

[100] CAWS data showed that the fuel balancing system detected the 70-pound imbalance about 1327 and that the left fuel boost pump activated about 1328 (because of the system's 1-minute delay to determine whether an actual fuel imbalance was occurring).

(3) the right fuel boost pump was needed to maintain fuel system pressure to the engine. Also, the fuel system configuration (which ensured a continuous, one-way flow of fuel to the engine, as shown in figure 3), along with the relatively high output pressure of the right-side fuel system, would have isolated any fuel flow provided by the left-side fuel system (because of the relatively low output pressure of the left-side fuel system at the time). As a result, the NTSB concludes that, about 1 hour 21 minutes into the flight, the fuel supplied to the airplane's engine was being drawn solely from the right fuel tank by the right fuel boost pump, and the left-wing-heavy fuel imbalance continued to increase.

The Pilatus PC-12 AFM stated that the fuel balancing system was designed to automatically correct fuel imbalances of up to 270 pounds, or about a six-bar differential on the fuel quantity indicator. If the left fuel boost pump had been automatically commanded by the fuel balancing system to turn on continuously, then the pump should have turned off once the fuel imbalance exceeded 270 pounds, which was estimated to have occurred about 1 hour 32 minutes into the flight (about 1342).[101] The CAWS data recorded no discernible change in the left fuel boost pump's status at this time (with the left fuel boost pump on continuously). Thus, the pilot had most likely recognized the fuel imbalance sometime between 1 hour 21 minutes and 1 hour 32 minutes into the flight and responded by repositioning the left fuel boost pump's switch (located on the overhead panel) from its AUTO to ON position.[102] This action allowed the left fuel boost pump to remain on continuously regardless of commands from the automatic fuel balancing system or the automatic activation of the pump in response to a low fuel pressure state.

In addition, the Pilatus PC-12 AFM instructed pilots to monitor the fuel quantity indicator for fuel symmetry during each flight. About 1 hour 32 minutes into the flight, the fuel quantity indicator would have displayed a six-bar differential between the left and the right fuel tanks. The AFM stated that the maximum fuel imbalance for the PC-12 was 178 pounds with a maximum three-bar differential displayed on the fuel quantity indicator. The pilot elected to continue to BZN, even though the maximum three-bar differential had been exceeded. (This issue is further discussed in section 2.2.5.)

The left fuel boost pump was on continuously and the right fuel boost pump was cycling until 1 hour 52 minutes into the flight (about 1402). At that time, the left fuel boost pump was off for 11 seconds and was then on continuously. Also, the right fuel boost pump was on continuously for 20 seconds and then resumed cycling. The brief change in the status of both fuel boost pumps was most likely induced by the pilot. Specifically, the pilot most likely recognized that the fuel imbalance was not being corrected and, as a result, repositioned the left fuel boost pump switch from ON to AUTO and the right fuel boost pump switch from AUTO to ON to observe the effect that the changed switch state would have on the fuel boost pumps'

[101] All fuel imbalance estimates in this analysis are based on the following assumptions: (1) an equal lateral fuel burn of 200 pounds during the flight from VCB to OVE, which would have resulted in 1,268 pounds of fuel in each tank when the accident flight leg began, and (2) a calculation of the fuel consumption and redistribution required for the activation of the R FUEL LOW caution toward the end of the flight (as discussed later in this section).

[102] The Pilatus PC-12 AFM stated that fuel symmetry could be maintained (if the fuel balancing system were unable to maintain lateral fuel symmetry or if automatic fuel balancing were inhibited by a lateral fuel asymmetry that exceeded 270 pounds) by manually selecting the fuel boost pump switch to the ON position for the tank with the higher fuel quantity. The AFM indicated that, once a balanced fuel condition was restored, the fuel boost pump switch should be returned to the AUTO position.

operation.[103] Similar switch repositioning activities occurred later in the flight, which were attributed to the pilot's attempts to rebalance the lateral fuel load through manual activation of the fuel boost pumps.[104]

About 2 hours 17 minutes into the flight (about 1427), the CAWS annunciated a right fuel low (R FUEL LOW) caution; the Pilatus PC-12 AFM stated that this caution was logged when the amount of usable fuel in a tank (in this case, the right wing tank) was 133 pounds or less.[105] The expected fuel load at this point in the flight, assuming 1,268 pounds of fuel in each tank (1,252 pounds of which was usable fuel) at the beginning of the flight and equal fuel consumption from each tank during the flight, would have been 812 pounds of usable fuel per tank. However, the fuel load at the time of the R FUEL LOW caution was estimated to be 1,368 pounds (1,352 pounds of which was usable fuel) in the left tank and 149 pounds (133 pounds of which was usable fuel) in the right tank, which corresponded to a left-wing-heavy imbalance of 1,219 pounds. This imbalance would have been displayed to the pilot on the fuel quantity indicator as a 26-bar differential.

Five seconds later, the right fuel boost pump turned on continuously and remained that way until the end of the flight. (The left fuel boost pump had been on continuously since about 1426 and remained that way until the end of the flight.) At the time of the last CAWS entries for the flight (about 1433), the fuel imbalance would have been displayed to the pilot as a 27-bar differential. (Each side of the fuel quantity indicator contains a total of 28 bars.)

Table 9 shows the fuel load throughout the accident flight leg. Between 1231 and 1235, a right-wing-heavy fuel imbalance existed (which was resolved by the normal operation of the automatic fuel balancing system to laterally balance the fuel load); beginning about 1323, a left-wing-heavy fuel imbalance existed. The flight times shown in the table correspond to key events during the flight, as described in section 2.2.3 and this section.

Table 9. Fuel balance estimates.

Time in flight	Local time	Amount of fuel used (in pounds)	Amount of total fuel remaining (in pounds)		Imbalance (in pounds)	Bar differential on fuel quantity indicator
			Left tank	Right tank		
0:00:00	1210	26	1,271	1,271	0	0
0:21:04	1231	204	1,147	1,217	70	2
0:22:04	1232	212	1,141	1,215	74	2
0:25:49	1235	237	1,166	1,166	0	0

103 The automatic fuel balancing system would not have commanded the left fuel boost pump to operate continuously at this time because the fuel imbalance had already exceeded the 270-pound differential limit of the system.

104 For example, at 2 hours 5 minutes into the flight (about 1415), the right fuel boost pump was on continuously, and the left fuel boost pump was off. Also, about 3 minutes later (about 1418), the left fuel boost pump was on continuously, and the right fuel boost pump was cycling. In addition, at 2 hours 10 minutes into the flight (about 1420), the right fuel boost pump was on continuously, and the left fuel boost pump was off. Finally, about 6 minutes later (about 1426), the left fuel boost pump was on continuously, and the right fuel boost pump was cycling.

105 After the accident, Pilatus published an emergency procedure for low fuel quantity in the PC-12 AFM (see section 1.6.4.2).

Time in flight	Local time	Amount of fuel used (in pounds)	Amount of total fuel remaining (in pounds)		Imbalance (in pounds)	Bar differential on fuel quantity indicator
			Left tank	Right tank		
1:13:32	1323	550	1,034	984	50	1
1:16:59	1326	570	1,033	965	68	1
1:17:59	1327	576	1,033	958	75	1
1:18:09	1328	583	1,030	955	75	2
1:21:05	1331	602	991	976	15	0
1:32:00	1342	667	1,087	814	273	5
1:52:08	1402	802	1,249	517	732	16
2:05:28	1415	881	1,367	320	1,047	22
2:07:00	1417	886	1,368	298	1,070	22
2:08:36	1418	898	1,368	274	1,094	23
2:10:34	1420	909	1,368	245	1,123	24
2:16:21	1426	944	1,368	160	1,208	25
2:17:05	1427	950	1,368	149	1,219	26
2:23:22	1433	979	1,368	66	1,302	27

Note: The calculations for the amount of fuel remaining and the fuel imbalance are based on the 1,368-pound total fuel capacity for each wing fuel tank. The calculations for the bar differentials shown on the fuel quantity indicator are based on the 1,352-pound usable fuel capacity for each tank.

As previously stated, beginning about 1331, the fuel supplied to the engine was being drawn solely from the right wing fuel tank by the right fuel boost pump. With the fuel return system operating normally, any excess fuel flow to the engine would have been returned and distributed equally to both fuel tanks.[106] Thus, the NTSB concludes that the left and right fuel tanks were equally receiving fuel through the fuel return lines but that the left-wing-heavy fuel imbalance continued to increase during the flight because fuel was only being drawn from the right fuel tank. The increasing fuel level in the left tank and the accelerated depletion of the fuel from the right tank should have been apparent to the pilot because that information would have been presented on the fuel quantity indicator.

The right fuel boost pump was providing all of the fuel system pressure to the engine because the left-side fuel system was no longer able to maintain the required fuel pressure through the operation of the left fuel boost pump. (At that time, the fuel pressure output was less than 2 psi, even with the left fuel boost pump on continuously.) The circumstances resulting in the low fuel pressure state and the degraded performance of the left-side fuel system (which restricted access to the fuel contained within the left wing tank and led to the left-wing-heavy fuel imbalance) were not resolved at any time during the flight; a possible cause for these conditions is discussed in section 2.2.4. Nevertheless, the NTSB concludes that the fuel system continued to provide fuel to the engine throughout the flight, even with the low fuel pressure state and the degraded performance of the left-side fuel system.

2.2.3.2 Descent Into the Terminal Area and Impact

Radar data showed that, at 1402:52, the pilot changed the airplane's route of flight and turned to the left toward BTM without ATC clearance. As shown in table 9, the pilot would have

[106] About 1417, the left tank had reached its 1,368-pound total capacity (1,352 pounds of which was usable fuel), so any excess fuel from that point in the flight onward would have been vented overboard. The total amount of fuel vented overboard was estimated at 91 pounds.

seen a 15-bar differential on the fuel quantity indicator about that time; the maximum allowable fuel imbalance according to the PC-12 AFM was three bars. Also, CAWS data showed that, before the airplane's course change, the pilot was unsuccessful in his attempts to laterally balance the fuel load by changing the status of the fuel pumps. The NTSB concludes that, although the pilot should have diverted to land the airplane as soon as practical after his attempt to restore fuel balance within the maximum imbalance limitation was unsuccessful, his eventual decision to divert to BTM likely resulted from his recognition of the magnitude of the increasing left-wing-heavy fuel imbalance situation.

The pilot contacted the controller at 1403:25 to request a change in destination to BTM but did not provide a reason for this request. The controller then cleared the airplane direct to BTM. The airplane began descending from FL250 (as previously assigned by ATC) at 1404:09 but again without clearance to do so. At 1404:24, the pilot contacted the controller to request a lower altitude, and the controller cleared the airplane to descend at the pilot's discretion to an altitude of 14,000 feet. CAWS data showed that, about 1405, the autopilot disengaged.[107]

At 1405:23, the pilot transmitted a second request to change the flight's destination to BTM. The controller told the pilot that he had previously cleared the airplane to BTM. The pilot might have inadvertently repeated his request because he would have been preoccupied with handling the left-wing-heavy airplane. At this point, the left fuel tank was 88 pounds under its 1,368-pound total capacity, and the pilot would have seen a 17-bar differential on the fuel quantity indicator. To compensate for this imbalance, the pilot was likely manually inputting right aileron trim to maintain level flight (as discussed later in this section). Also, according to CAWS data, the pilot was still attempting to resolve the fuel imbalance by toggling the fuel boost pump switches to laterally balance the fuel load.

At 1406:15, the controller instructed the pilot to "advise receipt of Butte Montana weather and notams." The pilot responded, "wilco," indicating that he would comply with the instruction. However, the ATC transcript showed that the pilot did not acknowledge receipt of BTM weather and NOTAM information. The ATC transcript also showed that the controller (and the controller who took over the shift about 1419) did not follow up with the pilot to ensure that he had received BTM weather and NOTAM information. On March 18, 2010, the NTSB issued Safety Recommendation A-10-42, which asked the FAA to "establish and implement standard procedures to document and share control information, such as…the confirmation of the receipt of weather information, at air traffic control facilities that do not currently have such a procedure."[108] Safety Recommendation A-10-42 was classified "Open—Acceptable Response" on November 29, 2010.

CAWS data indicated that, about 1409, either the autopilot or the yaw damper was engaged. It is likely that the pilot had engaged the yaw damper, independent of the autopilot, to counter any yawing and rolling oscillations that the airplane was experiencing. CAWS data

[107] The NTSB could not determine whether the autopilot disengaged automatically or was disengaged manually by the pilot.

[108] BTM is an uncontrolled airport, and the Salt Lake ARTCC does not currently employ the recommended procedure.

further indicated that, from about 1415 to 1426, the pilot continued his efforts to resolve the fuel imbalance and laterally balance the fuel load.

Radar data showed that the airplane descended below 12,200 feet (the minimum IFR altitude for the area) at 1426:49 and continued descending. About this time, the CAWS annunciated the R FUEL LOW caution. The Pilatus PC-12 AFM required pilots, upon receiving this caution, to land as soon as possible. Even though the pilot was required to comply with the previously issued ATC altitude restriction of 13,000 feet until he had the airport in sight and could provide his own terrain clearance, it is likely that he continued his descent to the terminal area without clearance to do so because the airplane was likely becoming increasingly difficult to control. At that point, the left fuel tank was filled to capacity (1,368 total pounds and 1,352 usable pounds), and the right fuel tank contained 133 pounds of usable fuel, resulting in a 1,219-pound imbalance and a 26-bar differential on the fuel quantity indicator.

At 1427:27, the controller advised the pilot that BTM was at his 12:00 position and was 12 miles away. The pilot indicated that the airport would be in sight "as soon as we get past one more cloud." At 1428:43, the pilot reported that he had the airport in sight and canceled his IFR clearance. The controller then instructed the pilot to squawk VFR. Radar data showed that the airplane was 8 miles southwest of BTM at an altitude of 11,100 feet (5,550 feet agl). The airplane continued to squawk the previously assigned discrete transponder code during the next 1 1/2 minutes as the airplane continued toward BTM. The last recorded radar target, at 1430:25, showed that the airplane was at an altitude of 9,100 feet (3,550 feet agl) and about 1.8 miles southwest of the runway 33 threshold. At that time, the airplane had a 1,302-pound fuel imbalance, with 1,368 total pounds of fuel in the left tank and 66 total pounds of fuel in the right tank, and the fuel quantity indicator would have been displaying a 27-bar differential between the left and the right fuel tanks. The calculated groundspeed between the final two radar targets was about 189 knots.

BTM is located at an elevation of 5,550 feet, so the airplane needed to descend 3,550 feet within 1.8 miles (based on the final radar target), which would result in a descent rate of 5,000 feet per minute. Witnesses to the accident reported that the airplane was approaching runway 33 at a higher altitude than most airplanes that land at the airport. One of these witnesses stated that the airplane appeared to fly directly toward the end of the runway but seemed to be at too high of an altitude to complete the landing. The witnesses further stated that the airplane then flew northwest away from the runway and entered a sharp left turn at an estimated altitude of 300 feet agl. (Mountainous terrain in the area would have prevented the pilot from making a right turn.) The witnesses reported seeing the airplane roll to the left before entering a steep bank, pitching down, and impacting the ground. Wreckage evidence indicated that the landing gear was extended[109] and the flaps were fully retracted at the time of impact.

Postaccident examination of the engine revealed no evidence of any mechanical abnormalities that would have precluded the engine from producing rated power. No mechanical anomalies associated with the engine were recorded by the EIS or the CAWS. Physical

[109] Specifically, the left main, right main, and nose landing gear were found separated from the fuselage; the right main landing gear actuator was found extended; and a tire transfer mark from the right main landing gear was found on a gravestone just aft of where the landing gear was found within the debris field.

signatures observed during the engine and propeller postaccident examinations were consistent with the engine operating in a mid- to high-power condition at impact.

During further examination of the wreckage, the NTSB found the aileron trim actuator fully extended. This position correlated to full RWD aileron trim, which would counter a left roll tendency. (Pilatus found that, during PC-12 flight testing, the first indication of fuel asymmetry, in terms of aircraft handling, was the need to increase the amount of aileron trim.) The aileron trim actuator position was consistent with an extremely high volume of fuel in the left wing tank and a relatively low volume of fuel in the right wing tank because a greater fuel weight in the left wing tank required aileron input in the RWD direction to maintain a level roll attitude.[110]

The rudder trim actuator was also found fully extended, which correlated to full ANL rudder trim. The rudder trim function of the yaw damper system had likely trimmed the rudder automatically in the ANL direction.[111] This rudder trim position, along with the aileron trim position, would have placed the airplane in a forward right sideslip (with the airplane's nose yawed to the left), which would not be consistent with a left-wing-heavy fuel imbalance but would instead be consistent with creating drag and increasing the descent rate without increasing airspeed. The full ANL rudder trim would also have increased the control wheel forces required for the pilot to maintain control of the airplane.

Postaccident calculations prepared by Pilatus indicated that a fuel imbalance of about 1,300 pounds would require 22º (55 percent) of the aileron's full 40º range of travel and a 20-pound control wheel input (which is less than the 50-pound maximum pilot control wheel force allowed by 14 CFR 23.143). Pilatus' calculations indicated that the airplane would have been controllable to an airspeed of about 90 knots (which is just below the PC-12 stall speed of 93 knots) with the fuel imbalance that existed at the time of the accident.[112] However, Pilatus' postaccident calculations assumed static conditions (that is, an unaccelerated airplane state) and did not account for the airplane dynamics (that is, accelerations) associated with maneuvering and landing or the effects of the engine and the propeller during the left turn if the pilot had attempted to execute a go-around maneuver.

Also, Pilatus based its calculations on small sideslip angles and a control wheel force that did not account for other dynamic factors during the accident sequence, such as an increasing left rudder deflection and the resulting large left yaw angles. The NTSB conducted a PC-12 simulation, which was derived from and validated with a Pilatus simulation model. The pilot inputs associated with a forward slip were assumed in the simulation, but reduced power effects in a descent could also account for the ANL pilot input suggested by the position of the rudder

[110] The right wing exhibited relatively little fire damage compared with the left wing, which sustained extreme impact, explosion, and fire damage that were consistent with a high volume of fuel at impact.

[111] Pilatus conducted a study of the automatic flight control system's yaw damper/rudder trim relief mode after a PC-12 accident in 2008. Postaccident examination of the wreckage found that the rudder trim was fully positioned in the ANL direction. (Additional information about this accident, NTSB case number DEN08FA162, is available on the NTSB's website at <http://www.ntsb.gov/aviationquery/index.aspx>.) The study concluded that, during a descent with low engine power applied, left rudder pedal force (resulting in automatic yaw damper/rudder trim relief in the ANL direction) was required. Pilatus found that those conditions, which resulted in a fully trimmed ANL rudder position, were possible during a nominal flight profile.

[112] Pilatus' PC-12 certification flight testing was performed with fuel imbalances ranging between 240 and 380 pounds.

trim actuator as found in the wreckage. According to the results of the simulation, at 160 knots the pilot would have needed full RWD aileron trim, 13 pounds of wheel force, and about 1º of right rudder trim to control the fuel imbalance. These forces would increase to 31 pounds of wheel force and 54 pounds of left pedal force for a forward slip at the trim settings found in the wreckage. If the pilot relaxed the left pedal force, wheel deflection and sideslip angle would decrease. However, the left rudder trim and fuel imbalance would continue to roll the airplane to the left unless the wheel was deflected to the right and, ideally, the right pedal was also deflected. Adding power and increasing the load factor would increase the left rolling tendency and require additional right wheel and/or right pedal deflection.

As the pilot maneuvered the airplane near the approach end of the runway, a steep descent developed, and the impact damage and ground scars showed that the airplane was still in a substantial descent (but near wings level) when it impacted the ground. A large left roll angle also developed during the maneuver. The NTSB considered a possible reason why the large left roll angle developed: if the pilot had momentarily diverted his attention away from flying the airplane and, in doing so, had slightly relaxed his control force inputs to the wheel, then the roll to the left could have rapidly increased. A large roll angle would result in a nose-down pitch attitude and a rapidly increasing descent rate. Pulling back on the control wheel to arrest the descent rate would exacerbate the left rolling moment and would require an even greater right wheel deflection to control the increasing rolling moment to the left. However, the airplane had adequate control authority to partially recover from the large left roll angle and nose-down pitch attitude that were reported by the witnesses. As a result, the NTSB concludes that the airplane was controllable in static flight with the left-wing-heavy fuel imbalance that existed at the time of the accident but that the pilot did not maintain control of the airplane with the dynamic maneuvers during the final moments of the flight.

2.2.3.3 Lateral Fuel Imbalance Condition

Pilatus conducted a fuel system hazard assessment during PC-12 certification to comply with 14 CFR 23.1309, which required that any aircraft equipment, system, or installation perform its intended function under any foreseeable operating condition. The assessment considered the effects of an excessive fuel imbalance between both wing fuel tanks and found that the difference in fuel weight would produce a rolling moment on the aircraft, which could be counteracted by changing the trim setting.

The assessment further addressed a fuel imbalance between both wing fuel tanks that exceeded 25 percent of the full fuel tank load. Specifically, the assessment found that, with this imbalance, the resulting rolling moment could not be corrected by trimming alone, which would increase pilot workload and decrease the airplane's safety margin if a maneuver with higher-than-usual levels of piloting skill was required.

In addition, Pilatus' fuel system hazard assessment stated that, if the rolling moment resulting from the difference in fuel weight became too large to be counteracted by changing the trim setting, it might be necessary for the pilot to change the original flight to prevent an excessive rolling moment. The Pilatus PC-12 AFM addressed this situation by indicating that, when the fuel quantity indicator showed a difference of three or more bars between the left and the right fuel tanks, the pilot should land as soon as practical if the difference could not be balanced. Thus, the NTSB concludes that the large left rolling moment induced by the left-wing-heavy fuel imbalance could have been minimized or even avoided if the pilot had followed Pilatus' required procedures for flight operations with a fuel imbalance.

2.2.4 Cause for the Low Fuel Pressure State and Degraded Performance of the Left-Side Fuel System

The NTSB and Crane Aerospace conducted postaccident testing to determine the performance of exemplar model K fuel boost pumps (the pump model installed on the accident airplane) under three operating conditions: Jet A fuel with no water or FSII added, Jet A fuel with only water added, and Jet A fuel with both water and a FSII added. Each of the three operating conditions was tested at a temperature of -30º C.

The testing showed decreased fuel system performance during tests that did not include the use of a FSII and enhanced system performance during tests that included the use of a FSII. Specifically, during the test that involved jet fuel with no water or FSII added, the fuel flow rate decreased progressively over time because ice accumulation on the fuel flow valve in the test equipment constricted the fuel flow path. The decrease in the fuel flow rate was mitigated by adjusting and tapping on the fuel flow valve to break away the ice. For the test involving jet fuel with only water added, the degradation of fuel flow rate occurred more quickly because more ice accumulation was present on the fuel flow valve (compared with the ice accumulation on the valve during the test involving jet fuel only), so additional adjusting and tapping on the fuel flow valve were necessary to break away the ice. For both of these tests, fuel flow was restored after adjusting and tapping on the fuel flow valve because these actions removed the constriction.[113] For the test involving jet fuel with both water and a FSII added, the fuel flow rate remained relatively constant, and the FSII prevented ice from accumulating on the fuel flow valve.

One of the exemplar fuel boost pumps performed inconsistently during its initial test run at -30º C without water or a FSII added to the fuel. The pump returned to normal performance when it was tested at 0º C. An internal inspection of the pump found some operational abnormalities (pitting of one motor brush and excess brush material on the commutator surface). It is important to note that these abnormalities occurred only while the pump was running at a temperature associated with prolonged flight at high altitudes; no operational abnormalities were observed when the pump was running at a temperature associated with flight at lower altitudes or operations on the ground (including preflight testing). This finding showed that, even with the required preflight examination of the fuel boost pumps (to audibly verify pump operation), pilots might not be aware of a problem pump until the airplane was operating at high altitudes and with cold temperatures. In addition, ice accumulation on the test pump might have contributed to the pump's initial poor performance, which further emphasized the importance of a FSII during flight operations below 0º C.

Pilatus' emergency procedure for low fuel pressure at the time of the accident noted that low fuel pressure (as shown by the CAWS FUEL PRESS caution) would normally cause the fuel pumps to turn on automatically and cycle on and off every 10 to 15 seconds (as shown by the

[113] Although the fuel flow valve used during the tests is not part of the PC-12 fuel system, the test results demonstrated that ice accumulation could degrade a fuel system's performance.

L FUEL PUMP and R FUEL PUMP advisories). As stated in section 2.2.3.1, the fuel pressure caution was not logged at any time during the accident flight, even though the fuel boost pumps were cycling to resolve a low fuel pressure state. However, the procedure also indicated that the airplane should descend to warmer air when the fuel boost pumps were cycling because "a possible cause is the fuel filter blocked with ice crystals."

In June 2010, Pilatus revised its emergency procedure for low fuel pressure. The revised procedure stated that both the FUEL PRESS caution and the cycling of a FUEL PUMP advisory on and off every 10 seconds were indications of low fuel pressure. The NTSB believes that, even if the revised procedure for low fuel pressure had been in place at the time of the accident, the outcome of the accident would still have been the same because the pilot did not (1) add a FSII to the fuel, (2) descend to warmer air when the fuel boost pumps were cycling, and (3) divert to a suitable airport when the maximum allowable fuel imbalance had been exceeded (as discussed further in sections 2.2.5 and 2.2.6).

The importance of adding a FSII to fuel to prevent ice crystals from accumulating in the fuel filter was demonstrated during a January 2008 flight involving another Pilatus PC-12, N666M. Specifically, the pilot of that flight observed both fuel boost pump advisories illuminate steadily (indicating fuel pump cycling), and he heard a noise that sounded as if the fuel boost pumps were "struggling." At the time, the airplane was operating between FL230 and FL250 and with an outside air temperature of about -30º C. The pilot descended the airplane to warmer air, diverted to another airport, and landed uneventfully. After landing, the pilot took a fuel sample because he was concerned that the fuel did not contain a FSII, even though the FBO that had serviced the airplane told him that a FSII had been added to the fuel.[114]

The airplane's owner, who was aboard the airplane during the flight, indicated that the pilot suspected that the reason for the fuel boost pump operation was ice in the fuel system. The owner further indicated that the fuel sample that the pilot secured after the flight had ice crystals floating in it. Because the pilot subsequently serviced the airplane with fuel that contained a FSII and did not experience any further problems with the airplane, it is likely that the problem experienced during the flight resulted from the absence of a FSII, which caused the fuel system's performance to be degraded.

As previously stated, Pilatus required that a FSII be used for all flights operated with outside air temperatures below 0º C; the accident flight was operated in temperatures as low as -40º C. Evidence indicated that the accident pilot was aware of the need to add a FSII: the subject was discussed during recurrent training sessions, and fueling records between October 2007 and January 2009 indicated that the pilot always requested a FSII when fueling the airplane at San Bernardino.[115] The NTSB could not determine why the pilot did not add a FSII during the four times that the airplane was fueled at REI in February and March 2009 and during the fueling at VCB on the day of the accident. The pilot was aware that at least two of the three flight legs on

[114] Fuel records were not available to determine the amount of fuel that the airplane received at the FBO or whether a FSII had been added to the fuel.

[115] The only other available fueling record obtained during this accident investigation showed a fueling that occurred in Riverside, California, on March 30, 2007. The airplane was fueled with 206 gallons of Jet A fuel; a FSII was not added to the fuel. However, it is not clear whether a FSII would have been required for the flights for that day.

the day of the accident would be conducted at high altitudes and in cold temperatures and should thus have understood the need for a FSII.

In addition to the low fuel pressure state that existed during the accident flight, the left-side fuel system was not delivering fuel to the engine during much of the flight. The NTSB attempted to determine a possible reason for the restricted fuel supply from the left tank. Although the exact source of the restriction could not be identified, the postaccident testing clearly showed that ice accumulation in the fuel system (as a result of not adding a FSII) could degrade the performance of many fuel system components, including the fuel boost pumps and valves.

The NTSB concludes that the low fuel pressure state and the restricted fuel supply from the left tank during the accident flight were the result of an accumulation of ice in the fuel system with an initial concentrated amount of ice at the airframe fuel filter. The NTSB further concludes that, if the pilot had added a FSII to the fuel for the flights on the day of the accident, as required, the ice accumulation in the fuel system would have been avoided, and a left-wing-heavy fuel imbalance would not have developed. Recommended actions to promote the use of a FSII in aircraft requiring the additive are described in sections 2.3 and 2.4.

2.2.5 Airports Along the Airplane's Ground Track

As stated in section 2.2.3.1, the pilot elected to continue to BZN and did not comply with the PC-12 AFM requirement to land the airplane as soon as practical when the maximum allowable fuel imbalance between the left and the right tanks had been exceeded. This exceedance, as shown by a three-bar differential on the fuel quantity indicator, was estimated to have occurred shortly after 1331. Although the pilot eventually diverted to BTM (about 1402, when the difference between the left and the right fuel tanks would have been 15 bars), other possible diversion airports were located along the airplane's route of flight. These alternate airports included Boise Air Terminal/Gowen Field (BOI), Boise, Idaho; Challis Airport (LLJ), Challis, Idaho; Joslin Field/Magic Valley Regional Airport (TWF), Twin Falls, Idaho; and Dillon Airport (DLN), Dillon, Montana. All of these airports had at least one runway that was 3,000 feet in length or greater and were reporting VMC.[116]

About 1335, the airplane was located about 24 miles and 6 minutes flying time from BOI,[117] the first alternate airport along the airplane's route of flight. If the pilot had diverted to BOI sometime between 1335 and 1345 (when the airplane was 44 miles and 11 minutes from the airport), then the airplane would have arrived at BOI with an estimated fuel imbalance of 6 to 12 bars. After passing BOI, the closest alternate airport to the airplane's position about 1340 was TWF, which was located about 73 miles and 18 minutes away. However, TWF was southeast of the airplane's position and in the opposite direction of the route of flight. The next alternate airport, LLJ, was located about 91 miles and 22 minutes from the airplane's position about 1340.

[116] Two other airports along the airplane's route of flight—Pocatello Regional Airport, Pocatello, Idaho, and Idaho Falls Regional Airport—were also possible diversion airports. However, those airports were reporting instrument meteorological conditions or marginal VMC, and other possible diversion airports were closer to the airplane's position along the route of flight.

[117] Flight times in this section were based on a groundspeed of 250 knots.

At that time, the pilot most likely observed a fuel imbalance of five bars. If the pilot had initiated an immediate divert to either TWF or LLJ, the airplane would have arrived in the vicinity of each airport with an estimated fuel imbalance of 15 to 16 bars.

About 1400, the airplane was located about 16 miles and 4 minutes southeast of LLJ. Despite the airplane’s proximity to LLJ and an estimated fuel imbalance of 15 bars, about 1402 the pilot initiated the divert to BTM, which was located about 119 miles and 29 minutes away. By 1405, while established on its new flightpath to BTM, the airplane passed LLJ. The next alternate airport along the route of flight, DLN, was located about 63 miles and 15 minutes to the northeast of the airplane’s position. About 1415 and with an estimated fuel imbalance of about 22 bars, the airplane passed about 30 miles and 7 minutes to the west of DLN. At that time, the airplane was still about 55 miles and 13 minutes from BTM.

Figures 6 and 7 show the airplane’s position along the route of flight in relation to the airports that were available for landing, the times and distances to the airports as the flight progressed, and the fuel imbalance at those times. The NTSB concludes that, if the pilot had diverted earlier in the flight to one of several suitable airports along the airplane’s route of flight, the outcome of this flight would likely have been different because the airplane would have had a less severe fuel imbalance and the pilot would not have had to contend with the airplane’s deteriorating performance as the imbalance steadily progressed.

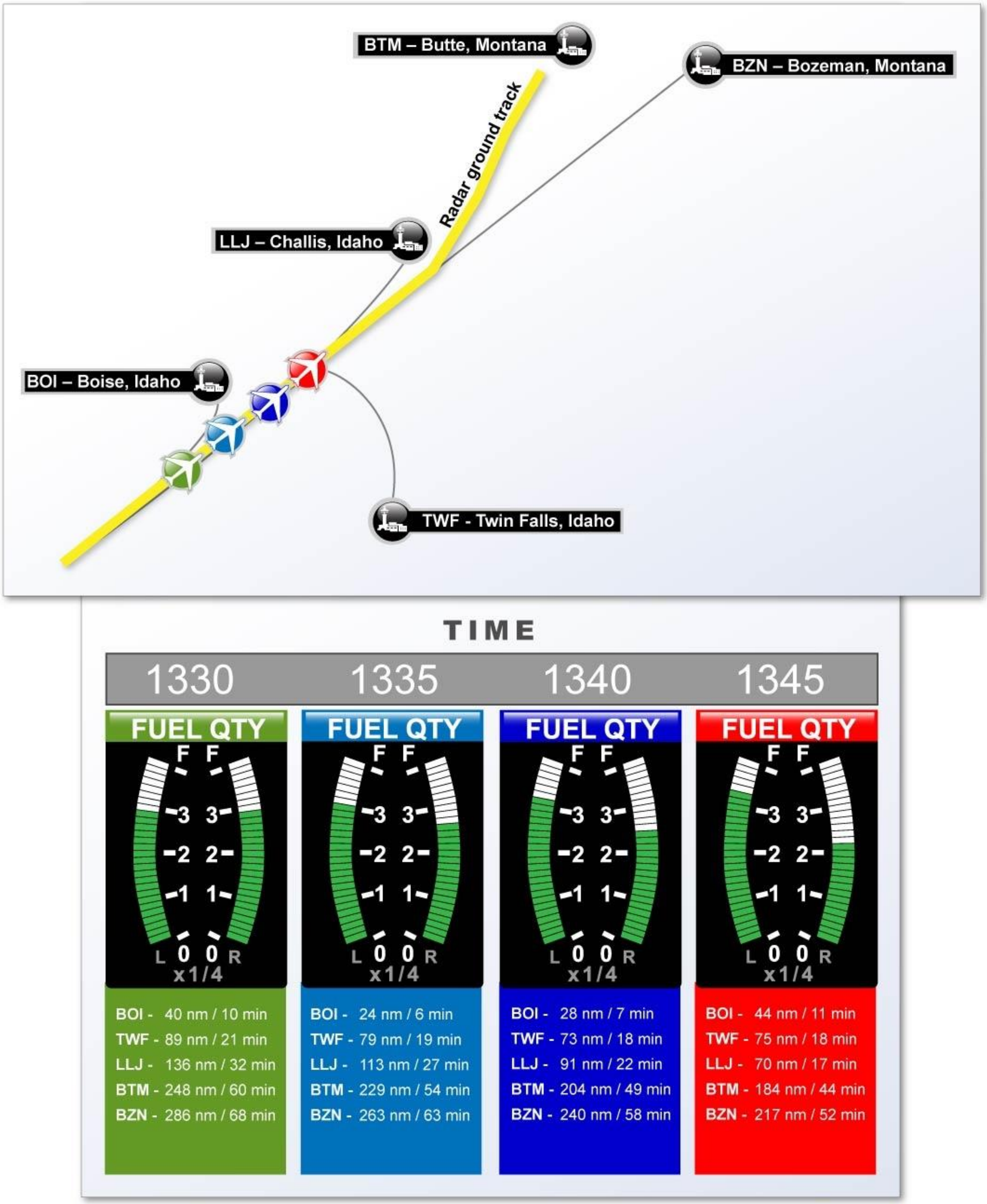

Figure 6. Available airports about the time of the maximum allowable fuel imbalance.

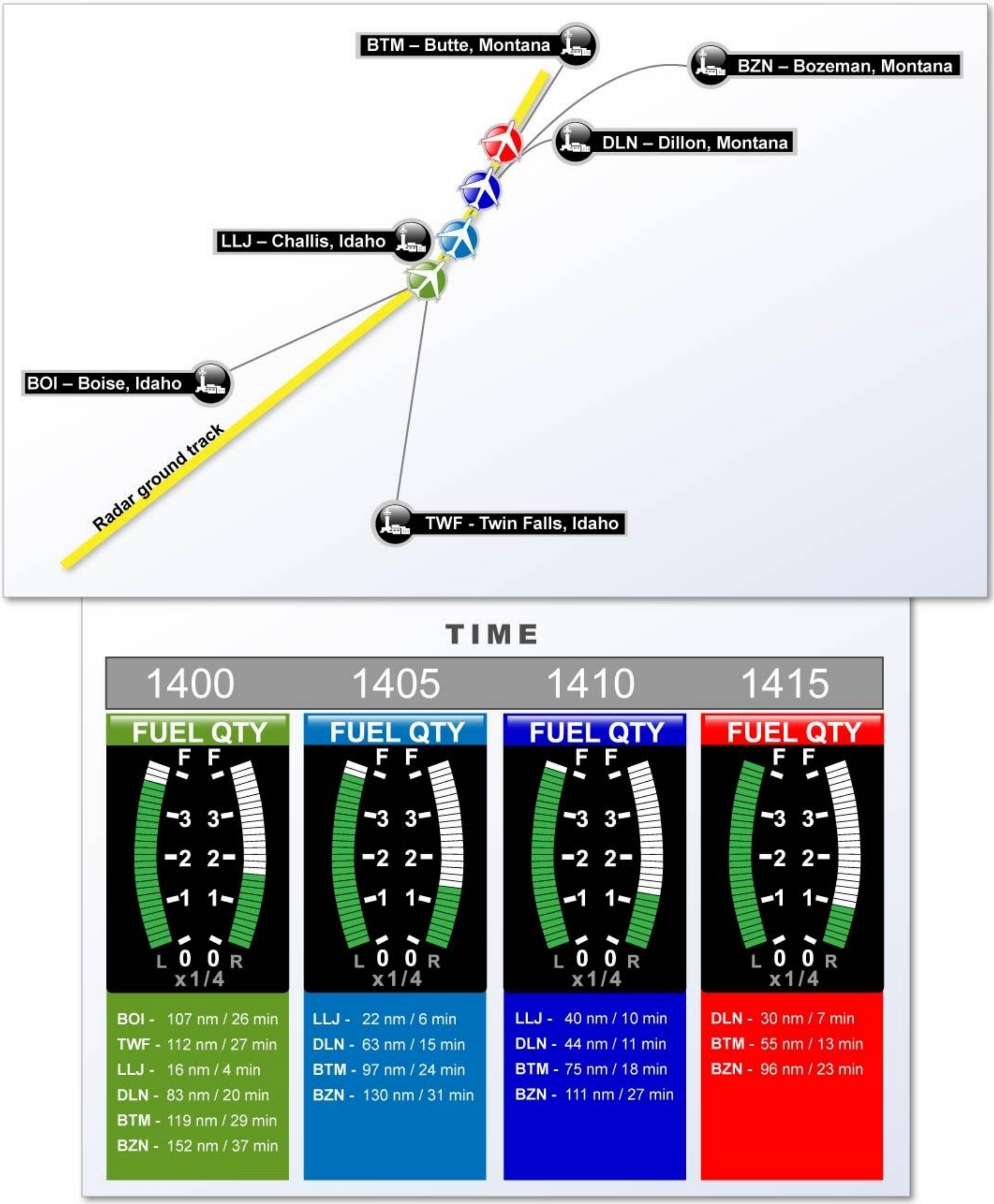

Figure 7. Available airports about the time of the diversion to Butte, Montana.

2.2.6 Pilot's Decision-Making

The pilot made several decisions that did not comply with established procedures in the PC-12 AFM, as described below. Some of these decisions ultimately affected the outcome of the accident flight.

- On the day before the accident flight, the pilot had the airplane fueled at REI but did not request that a FSII be added to the fuel, even though he was aware that at least two of the flights on the day of the accident (REI to VCB and OVE to BZN) would include operations at high altitudes and in cold temperatures. The PC-12 AFM required a FSII for operations in outside air temperatures below 0º C.
- Also on the day before the accident, the pilot filed three flight plans but misrepresented the number of occupants that would be on board the airplane during two of the flight legs.[118] Specifically, the flight plans indicated that five occupants, including the pilot, would be on board for the flight from VCB to OVE (10 occupants would actually be on board) and that nine occupants, including the pilot, would be on board for the planned flight from OVE to BZN (14 occupants would actually be on board). The pilot was aware that the airplane would have nine seats available to the 13 passengers and should have been aware of the AFM limitation allowing no more than nine passengers to be transported aboard a PC-12.
- For two of the three flight legs on the day of the accident, the pilot allowed the airplane to depart with a takeoff weight that was over the PC-12 maximum takeoff weight (see table 2).
- After arriving at VCB on the day of the accident, the pilot used the self-service fueling station to add fuel to the airplane, but he did not add a FSII to the fuel.
- The maximum allowable fuel imbalance between the left and the right fuel tanks was estimated to have been exceeded sometime between 1331 and 1335, and the pilot attempted to manually correct the imbalance sometime between 1331 and 1342. The PC-12 AFM stated that, if the fuel cannot be balanced, the pilot should land the airplane as soon as practical. The pilot did not divert to another airport at that time, even though three suitable airports along the airplane's route of flight—BOI, TWF, and LLJ—were available to the pilot.
- The pilot began to divert to BTM about 20 to 31 minutes after his attempt to restore fuel balance was unsuccessful. At that time, LLJ was the closest airport to the airplane's position. Once the airplane's route of flight changed, DLN became the most suitable diversion airport relative to the airplane's position, but the pilot decided to continue to BTM.

The NTSB evaluated fatigue as a possible factor in the pilot's decision-making process. Limited information was available about the pilot's sleep history in the days before the accident. On March 18, 2009, the pilot flew passengers aboard the accident airplane to Cabo San Lucas, departing REI about 1130 PDT and arriving at the destination airport about 3 hours later.

[118] On the day before the accident, the pilot acknowledged a trip plan modification (see section 1.5), recognizing that the airplane would be transporting a total of 13 passengers to BZN.

Afterward, the pilot stayed at a nearby hotel until the return trip. The airplane departed Cabo San Lucas on March 21 about 1030 PDT and arrived at REI about 1530 PDT. On March 22, the pilot departed REI about 0742 on the first leg of the accident trip. The accident occurred about 7 hours later. The pilot sustained fatal injuries during the accident, and his wife declined to be interviewed by the NTSB. Thus, no information could be obtained about sleep and other relevant fatigue factors. As a result, insufficient information was available to determine whether fatigue played a role in this accident.

The pilot had previously ignored indicators similar to those presented during the accident flight. Specifically, although CAWS fuel pump advisories were annunciated during the first leg of the accident trip, the pilot did not seek maintenance assistance at VCB or add a FSII during refueling at VCB. Also, CAWS fuel pump advisories were annunciated to the pilot during an October 2007 flight aboard the accident airplane (see table 5), but the NTSB found no evidence indicating subsequent pilot or maintenance action in response to the annunciations.

The pilot did not change his course of action during the accident flight leg in response to mounting indications to do so. The initial indications were the abnormal number of CAWS fuel boost pump activation advisories, which, as the flight progressed, were followed by the increasing fuel imbalance indications on the fuel quantity indicator and the need for increased opposite aileron deflection to counter the airplane’s increasing roll tendency toward the heavier wing. The pilot had likely downplayed the seriousness of the initial indications because no adverse outcomes resulted from ignoring similar indications during the first flight of the day and during the October 2007 flight. During the accident flight, rather than divert before the fuel imbalance became more severe, the pilot decided to continue to BZN, and the situation became more difficult to manage as the flight continued.

It is likely that the pilot wanted to deliver the passengers to BZN for their convenience and that he continued with this plan until he believed that he had no other option except to divert. The pilot’s decision to divert to BTM may also have been influenced by passenger convenience considerations. Specifically, the passengers could have easily arranged for ground transportation from BTM to their destination; such arrangements would have been more difficult from LLJ or DLN, which were the most suitable airports at the time that the pilot began to divert to BTM.

The pilot had not previously flown into BTM, so he might not have considered the BTM environment in his decision to divert to that airport. BTM is located in a valley surrounded by rising mountainous terrain (as shown in figure 2). The airplane approached BTM from the southwest over the mountainous terrain, but the limited distance between the mountain peaks and the airport restricted the pilot’s ability to maneuver the airplane during the descent. (Although DLN and BZN are also located in mountainous terrain, they are situated in wide open valleys, which might have accommodated a more gradual descent into the airport area.[119] The pilot had flown into BZN about 1 year before the accident occurred.)

Corporate pilots can experience pressures from airplane owners in addition to those pressures that they place on themselves. The instructor who provided the pilot’s recurrent training stated that the pilot had not experienced any undue pressure from the owners to fly in

[119] BZN is located about 57 miles east of the accident site at an elevation of 4,473 feet.

unsafe conditions. (The NTSB notes that transporting more passengers than available seats is an unsafe condition.)[120] The pressure on the pilot to continue to BZN and delay diverting to an alternate airport until the fuel imbalance became extreme was likely self-induced and was the result of improper decision-making as the flight progressed.

Postaccident interviews revealed positive reports of the pilot's skills and abilities. However, during the accident flight, the imbalance between the left and the right fuel tanks continued to increase, and the pilot found himself in a situation that he had not previously experienced. Also, it is possible that the pilot may not have fully understood the effects of fuel system icing, even with his previous history of always requesting a FSII when the airplane was based at San Bernardino. Nevertheless, the NTSB concludes that the pilot underestimated the seriousness of the initial fuel imbalance indications because he had not experienced any adverse outcomes from ignoring similar indications during previous flights.

2.3 Fuel Limitations and Placards

Section 2 of the PC-12 AFM, Limitations, detailed the requirements for FSIIs. The section stated that a FSII must be used for all flight operations in ambient temperatures below 0° C. The section further specified that the concentration of FSII must be between 0.06 and 0.15 percent by volume. A caution advised operators and pilots that the correct mix of anti-icing additive with the fuel was important because concentrations greater than 0.15 percent by volume would cause damage to the protective primer and sealants of the fuel tanks, the fuel system, and engine components. Section 8 of the AFM, Handling, Servicing, and Maintenance, contained the same caution but also included the statement, "concentrations [of FSII] lower than 0.06 [percent by volume] may not be enough to inhibit ice formation."

The NTSB is aware of three other turbine-powered single-engine airplanes that require a FSII: the Cessna 208B, Piper PA-46-500TP, and Socata TBM-700C.[121] The AFM for each of these airplanes provided information about the correct FSII usage directly in the limitations section or included a reference in the limitations section to another AFM section that contained specific FSII information. However, the use of cautions and warnings to highlight FSII information was inconsistent among the manuals.

Title 14 CFR 23.1583, "Operation Limitations," paragraph (b), states that AFMs must specify powerplant limitations, including the fuel designation for turbine-powered airplanes. However, the powerplant limitations information does not reference the requirement for FSIIs or other fuel additives. If a FSII is required by an airframe manufacturer, then the additive is a critical fuel system limitation, and the omission of a FSII from fuel (when required) could lead to

[120] The airplane owner who organized the accident trip was aware that 13 passengers would be transported aboard an airplane with only 9 passenger seats, stating after the accident that "there were just not enough seatbelts," and the pilot complied with this arrangement.

[121] The Prist Aerospace Products website (<http://www.pristaerospace.com>, accessed June 10, 2011) indicated that the following twin-engine aircraft require a FSII: Beechcraft Raytheon Beechjet 400 and Starship; Bombardier Learjet 23, 24, 25, 28, 29, and 35/36; Cessna Corsair/Conquest and Citation I and II; Hansa HFB-320; Mitsubishi MU-2 and MU-300; and Piaggio Avanti. The website also indicated that some very light jets (referred to as VLJs) require a FSII.

a situation resulting in personal injury or loss of life, as demonstrated by the circumstances of this accident.

AC 25.1581-1, "Airplane Flight Manual," dated July 14, 1997, identified the information that must be provided in AFMs for transport-category airplanes and provided guidance regarding the form and content of the approved portions of the AFMs. The AC stated that AFM operating procedures and techniques could be categorized as warnings or cautions. A warning was defined as "an operating procedure or technique that may result in personal injury or loss of life if not followed." A caution was defined as "an operating procedure or technique that may result in damage to equipment if not followed."

The safety hazard involving fuel system ice accumulation could be mitigated if manufacturers of aircraft requiring FSII for operation placed a warning within the limitations section of their respective AFMs that described the need to ensure that fuel contained the additive in a concentration between the specified minimum and maximum values. Therefore, the NTSB recommends that the FAA and the European Aviation Safety Agency (EASA) amend certification requirements for aircraft requiring fuel additives, including FSIIs, so that those limitations are highlighted by a warning in the limitations section of the AFM. The NTSB further recommends that the FAA and EASA require all existing certificated aircraft (both newly manufactured and in-service aircraft) that require fuel additives, including FSIIs, to have those limitations highlighted by a warning in the limitations section of the AFM.

In addition, the PC-12 fuel filler placard, which was located near each fuel filler port, specified the total fuel capacity (203 gallons) and usable capacity (201 gallons) for each fuel tank and the type of fuel to be used (Jet A, Jet A-1, or Jet B). The placard, however, did not note the requirement for a FSII during flight operations with outside air temperatures below 0º C. The PC-12 fuel filler placard was consistent with the requirements of 14 CFR 23.1557, "Miscellaneous Markings and Placards," which stated that fuel filler openings for turbine-powered airplanes must be marked at or near the filler cover with the words "Jet Fuel" and either the permissible fuel designations or references to the AFM for the permissible fuel designations. The regulation does not specifically require manufacturers to reference any necessary fuel additives on the fuel filler placard.

AC 20-29B, "Use of Aircraft Fuel Anti-Icing Additives," indicated that the use of a FSII would meet the provisions of 14 CFR 25.997(b), which required, at the time of the AC's issuance, "a means to automatically maintain the fuel flow if ice-clogging of the [fuel] filter occurs." Further, the AC stated that, for aircraft requiring a FSII, placards near the fuel filler cover should indicate that the fuel must contain the anti-icing additive.

Title 14 CFR 23.997(d) contained the same requirement as 14 CFR 25.997(b) but for normal- and commuter-category aircraft with turbine engine fuel systems. These regulations, however, did not provide protection for ice accumulation in other fuel system components. As a result, the requirements of both regulations were subsequently included in 14 CFR 23.951 and 25.951, "Fuel System, General." Specifically, sections 23.951(c) and 25.951(c) both required that the entire fuel system be capable of sustained operation throughout its flow and pressure range with water-saturated fuel cooled to the most critical condition for icing to be encountered during operation. It is important to note that the FAA did not include a related provision from

AC 20-29B in sections 23.951(c) and 25.951(c) when they first became effective or in any revision to the regulations since that time: for manufacturers of airplanes that used a FSII for meeting regulatory requirements to indicate, on fuel filler placards, the need to add a FSII to the fuel.

The Cessna 208B, Piper PA-46-500TP, and Socata TBM-700C all have fuel filler placards with a reference to FSIIs in addition to the information required by 14 CFR 23.1557. These fuel filler placards state, "anti-ice additive required. See Pilot's Operating Handbook for other approved fuels, quantity and type of additive." This placarded information provides a prominent reminder to pilots and fuel service personnel of the importance of a FSII during flight operations.

The NTSB concludes that the safety hazard involving fuel system ice accumulation could be mitigated if fuel filler placards installed aboard aircraft requiring a FSII specified that requirement. Therefore, the NTSB recommends that the FAA and EASA amend aircraft certification fuel placarding requirements so that aircraft requiring fuel additives, including FSIIs, have a fuel filler placard that notes this limitation and refers to the AFM for specific information about the limitation. The NTSB further recommends that the FAA and EASA require all existing certificated aircraft (both newly manufactured and in-service aircraft) that require fuel additives, including FSIIs, to have a fuel filler placard that notes this limitation and refers to the AFM for specific information about the limitation.

2.4 Guidance on Fuel System Icing Prevention

On October 22, 1981, the FAA issued AC 20-113, "Pilot Precautions and Procedures to Be Taken in Preventing Aircraft Reciprocating Engine Induction System and Fuel System Icing Problems." Although this AC detailed pilot precautions and procedures to prevent fuel system icing in aircraft with reciprocating (piston-driven) engines, including the use of anti-icing fuel additives, no AC addresses the prevention of fuel icing problems on turbine engine-powered aircraft. It is possible that turbine engine-powered aircraft were not addressed in AC 20-113 because most Part 91 and 135 aircraft operations at that time were conducted with piston engine-powered aircraft. However, many aircraft that are currently operating under Parts 91 and 135, such as the Pilatus PC-12, have turbine-powered engines. Such aircraft operate in cold temperatures and at high altitudes with service ceilings ranging from FL230 to FL310. As a result, pilots and operators of turbine engine-powered aircraft would also benefit from FAA guidance on preventing fuel system icing problems.

Pilots and operators of turbine-powered airplanes would further benefit from FAA guidance advising that the use of a FSII could substantially inhibit fuel system icing during flights at high altitudes and cold temperatures. Although pilots and operators of these airplanes should already understand the importance of adhering strictly to the limitations outlined in an airplane's AFM for operations requiring a FSII, FAA guidance would be another resource that promotes awareness of, and adherence to, required procedures designed to prevent fuel system icing problems in turbine-engine aircraft.[122] In addition, it is important for such guidance to

[122] Pilots could apply this guidance to preflight planning activities, including (1) determining whether fuel premixed with a FSII would be available at departure airports or whether the FSII would need to be directly injected

clearly explain the potential consequences of either failing to add a FSII when required, as demonstrated by this accident, or having an incorrect concentration of a FSII in jet fuel. Further, the guidance could be a means for informing pilots and operators of the availability of portable test kits to determine whether the correct concentration of a FSII is present in jet fuel.

The NTSB concludes that FAA pilot and operator guidance on the use of FSIIs would help raise awareness of the need to include this additive in turbine engine-powered aircraft with fuel systems that require the additive. Therefore, the NTSB recommends that the FAA issue guidance on fuel system icing prevention that (1) includes pilot precautions and procedures to avoid fuel system icing problems aboard turbine engine-powered aircraft and (2) describes the possible consequences of failing to use a FSII, if required by the AFM, especially during operations at high altitudes and in cold temperatures. This recommendation could be addressed by augmenting the guidance provided in AC 20-113.

2.5 Crash Protection for Airplane Occupants

On the day before the accident, the pilot filed three IFR flight plans. The first flight plan indicated that he would be the sole occupant of the flight from REI to VCB. The second flight plan, from VCB to OVE, indicated that a total of five people would be on board the airplane. However, nine people (four adults and five children), in addition to the pilot, were on board the airplane before it departed for OVE. Although the NTSB's calculations indicated that the airplane departed VCB weighing about 432 pounds more than the maximum allowable gross takeoff weight, the calculations also showed that the airplane was within the estimated forward and aft center-of-gravity limits for the weight of the airplane.

The airplane was configured with eight passenger seats in the cabin and two pilot seats in the cockpit. Because each flight on the day of the accident was a single-pilot operation, the eight seats in the cabin and the right seat in the cockpit were available to the nine passengers. Thus, the number of airplane occupants at this point in the trip did not exceed the number of available seats. Also, the number of airplane occupants at this time was in compliance with the Pilatus PC-12 AFM requirement indicating that the maximum number of occupants (for a corporate commuter configuration) was nine passengers plus pilot(s).

For the third flight plan, from OVE to BZN, the pilot indicated that a total of nine people would be on board, but four additional passengers (two adults and two children) boarded the airplane at OVE, resulting in a total of 14 people (the pilot and 13 passengers) aboard the airplane for the planned trip to BZN. Thus, the operation was not in compliance with the Pilatus PC-12 AFM requirement limiting the maximum number of passengers to nine. Also, the operation was not in compliance with 14 CFR 91.9, "Civil Aircraft Flight Manual, Marking, and Placard Requirements," which states in paragraph (a), "no person may operate a civil aircraft without complying with the operating limitations specified in the approved Airplane or Rotorcraft Flight Manual."

into the fuel and (2) learning whether a FSII would be available at destination airports or airports along the airplane's route of flight (if refueling would be needed) and, if not, determining what contingency plans could be made.

Postaccident calculations showed that the airplane departed OVE weighing about 572 pounds more than the airplane's allowable gross takeoff weight, but the airplane still remained within the estimated forward and aft center-of-gravity limits for the weight of the airplane. The NTSB found no evidence that the pilot performed a written weight and balance computation for this and the previous flight legs, but it is possible that he used an alternate means to perform the computations.[123]

The owner of the airplane who organized the trip stated that the airplane had transported the same number of passengers on a previous flight. For that flight and the accident flight leg, the owner believed that he and the pilot "were not pushing the envelope" because "the trip was within weight and balance limits," but the owner acknowledged that "there were just not enough seatbelts" for every passenger.

Except for the pilot and the adult passenger in the right cockpit seat, the NTSB was unable to determine the seating position for the airplane occupants. The airplane owner who organized the trip stated that the adults could hold the children on their laps. However, only one of the seven children was under the age of 2 years and was permitted by 14 CFR 91.107(a)(3)(i) to be held on the lap of an adult. The six other children ranged in age from 3 to 9 years. Because the bodies of four of these children were found farthest from the impact site, the NTSB concludes that at least four of the seven children on board the airplane were not restrained or were improperly restrained.

Proper restraint use is one of the most basic and important tenets of crashworthiness and survivability. However, 14 CFR 91.107 does not specifically prohibit multiple occupants from sharing one seating position.[124] Research by the United Kingdom's Civil Aviation Authority (CAA) documented problems with dual occupancy of a seat and restraint system designed for one adult passenger. Specifically, the CAA's research found that seating two children in the same seat and restraining both under one lap belt[125] (1) provided neither child with the same protection that they would have received if they were in separate seats and (2) increased the risk of both children sustaining head and body injuries during an impact.[126] In addition, even though section 91.107 allows children who are less than 2 years of age to be held on the lap of an adult,

[123] FAA operations inspectors indicated that, instead of using a written weight and balance form, pilots could use a calculator or mental math to determine whether an airplane was within weight and balance parameters.

[124] In January 2010 correspondence to the NTSB, the FAA stated that, according to section 91.107, multiple (two or more) occupants are allowed to share one seat and one restraint system as long as "the seat usage conformed with the limitations contained in the approved portion of the Airplane Flight Manual" and "the belt was approved and rated for such use."

[125] Each passenger seat aboard the accident airplane was equipped with lap and shoulder harness restraints. Although the CAA's research was conducted using lap belts, the NTSB believes that the findings would also apply to multiple occupants sharing a restraint system with a shoulder harness because the effectiveness of the shoulder harness would be reduced and the risk of injury to the occupants would thus increase. A shoulder harness is designed to prevent injury as a result of an occupant's head and torso flailing in an accident with a horizontal component. A single shoulder harness cannot provide restraint for two occupants because the harness would not fit either occupant properly.

[126] Roger N. Hardy, "Dual Child Occupancy of an Aircraft Seat," CAA Paper 93013 (London, United Kingdom: Civil Aviation Authority, 1993).

recent FAA guidance emphasizes that the safest place for a child under 2 years of age during turbulence or an emergency is in an approved child restraint system and not on an adult's lap.[127]

The NTSB concludes that, although the number of passengers on board the airplane during the final flight leg did not comply with the PC-12 AFM limitation requiring no more than nine passengers, the four additional passengers on board the airplane did not directly affect the outcome of the accident. Further, although the BTM accident was not survivable, the NTSB concludes that, for survivable accidents, passengers aboard airplanes operating under Part 91 would be afforded better crash protection if each seat and restraint system were limited to only one passenger and children less than 2 years of age were restrained in an approved child restraint system. As stated in section 1.18.2.1, the NTSB issued Safety Recommendations A-10-121 and -122 to amend 14 CFR Part 91 to "require separate seats and restraints for every occupant" and "require each person who is less than 2 years of age to be restrained in a separate seat position by an appropriate child restraint system during takeoff, landing, and turbulence," respectively. These recommendations, which were issued in August 2010, were classified "Open—Acceptable Response" on January 31, 2011.

On June 23, 2011, the FAA published its Clarification of Prior Interpretations of the Seat Belt and Seating Requirements for General Aviation Flights. The FAA's proposal did not include a provision to prohibit the shared use of a seat and restraint system, which is currently allowed under Part 91. Instead, the proposal relies on the "good judgment of the pilot" to determine the proper method of restraint for children during operations conducted under Part 91. The NTSB is disappointed that the FAA did not provide true clarification on the issue, and the NTSB remains concerned that the improved crashworthiness standards required by Part 23 regulations are negated when two or more occupants share a seat and a restraint.

Safety Recommendation A-10-121 asked the FAA to amend Part 91 to require separate seats and restraints for every occupant. The FAA's proposal shows that the agency does not intend to amend the regulation. Title 14 CFR 121.311, "Seats, Safety Belts, and Shoulder Harnesses," and 135.128, "Use of Safety Belts and Child Restraint Systems," require separate seats and restraints for each passenger age 2 years and older. The addition of such a requirement to Part 91 regulations would help ensure the proper use of seating and restraint systems during this type of operation.

The NTSB continues to believe that Part 91 regulations do not promote effective occupant protection because multiple occupants sharing one seat and restraint system are less likely than single occupants to withstand deceleration forces during a survivable crash. As a result, Safety Recommendation A-10-121 is classified "Open—Unacceptable Response."

2.6 Flight Recorder Systems

The accident airplane did not have, and was not required to have, a CVR or an FDR installed. In February 2009, the NTSB issued Safety Recommendations A-09-10 and -11, which asked the FAA to require crash-resistant flight recorder systems aboard existing turbine-powered

[127] This information was obtained from the FAA's website <http://www.faa.gov/passengers/fly_children/crs> (accessed June 10, 2011).

aircraft that are not equipped with a CVR and an FDR. Safety recommendations addressing the need for these recorders have been on the NTSB's Most Wanted List since 2001, and the issue was included on the NTSB's June 2011 Most Wanted List.[128]

Information that was critical to this investigation was discovered by extracting data from the nonvolatile memory stored in the CAWS central advisory control unit. Without this information, the NTSB would not have been able to analyze the behavior of the airplane's fuel boost pumps. The nonvolatile memory data revealed the abnormal number of fuel boost pump activations during this flight, the flight from REI to VCB on the day of the accident, and an October 2007 flight,[129] which led to the postaccident fuel boost pump testing that demonstrated the important role of FSIIs during flight operations at cold temperatures.

For this investigation, it was fortunate that significant information was available from a data source that was not designed for accident investigation activities.[130] However, to support future accident and incident investigation activities and to increase the likelihood that data could be retrieved after an accident (storage devices for nonvolatile memory data sources are not crash protected), it is important that aircraft be retrofitted with the crash-resistant flight recorder system described in Safety Recommendations A-09-10 and -11. Specifically, the NTSB's recommendations indicated that a crash-resistant flight recorder system "should record cockpit audio, a view of the cockpit environment to include as much of the outside view as possible, and parametric data per aircraft and system installation" and should meet the specifications of EUROCAE document ED-155, "Minimum Operational Performance Specification for Lightweight Flight Recorder Systems." Such recorders are a reliable source of detailed accident investigation information.

The crash-resistant flight recorder system described in Safety Recommendations A-09-10 and -11 would have helped the NTSB determine additional information about the BTM accident scenario. Specifically, radar data were available only until the airplane descended to an altitude of 9,100 feet, so the flight recorder system would have provided investigators with information about the airplane's altitudes, airspeeds, and track from 9,100 feet to ground impact. Also, the flight recorder system would have captured any pilot conversations with the passengers (especially with the adult passenger in the right cockpit seat) about the fuel imbalance and the decision to divert. Further, it is possible that images of the cockpit instrumentation would have been recorded, especially the fuel quantity indicator (for fuel imbalance information), and that recorded images of the outside environment could have shown the airplane's attitude and position relative to the terrain surrounding BTM.

[128] The NTSB's Most Wanted List is a program to promote public awareness of and support for actions to prevent accidents and save lives.

[129] CAWS data revealed that, of the 480 flights recorded by the system, 337 fuel boost pump activations had been logged for the accident flight. The data also revealed that 176 fuel boost pump activations had been logged for the flight leg from REI to VCB on the day of the accident and that 260 fuel boost pump activations had been logged for an October 2007 flight from Cabo San Lucas to San Diego. For the other 477 flights recorded by the CAWS, the fuel boost pumps activated a total of 29 times.

[130] The download of the nonvolatile memory data was initially attempted using previously established methods, but the data extraction was unsuccessful because of the impact damage to the CAWS central advisory control unit sub-board (which maintained the components containing the nonvolatile memory chips). As a result, the data could only be retrieved using a chip-level extraction method.

It is important to note that, in March 2011, Pilatus Aircraft began equipping new-production PC-12/47E airplanes with a dedicated, crash-resistant, lightweight data recorder (manufactured by L3 Communications) that complies with ED-155 standards. Pilatus also issued an SB in February 2011 to retrofit existing PC-12/47E airplanes with the recorder. According to a Pilatus official, the decision to install these recorders as standard equipment was made to support future investigations because “it will be much quicker, easier and [possibly] the only way to determine the cause of an incident or accident,” especially if other sources of data are lost during an accident.

The NTSB concludes that, although the download of nonvolatile memory data provided key information in determining the circumstances that led to this accident, a flight recorder system that captured cockpit audio, images, and parametric data would have provided additional information about the accident that was not possible to determine from the downloaded nonvolatile memory data. In May 2011, as part of its report on the August 2010 de Havilland DHC-3T accident in Aleknagik, Alaska,[131] the NTSB reiterated Safety Recommendations A-09-10 and -11.

[131] See *Collision into Mountainous Terrain, GCI Communication Corp., de Havilland DHC-3T, N455A, Aleknagik, Alaska, August 9, 2010*, Aircraft Accident Report NTSB/AAR-11/03 (Washington, DC: National Transportation Safety Board, 2011) at < http://www.ntsb.gov/Publictn/A_Acc1.htm> .

3. Conclusions

3.1 Findings

1. The investigation found that the pilot was properly certificated and qualified in accordance with applicable Federal regulations. The investigation also found no evidence indicating any preexisting medical or behavioral condition that might have adversely affected the pilot's performance on the day of the accident.

2. The investigation found that the airplane was properly certified, equipped, and maintained in accordance with Federal regulations and that the recovered components showed no evidence of any preimpact structural, engine, or system failures.

3. The low fuel pressure state and the restricted fuel supply from the left tank during the accident flight were the result of an accumulation of ice in the fuel system with an initial concentrated amount of ice at the airframe fuel filter.

4. If the pilot had added a fuel system icing inhibitor to the fuel for the flights on the day of the accident, as required, the ice accumulation in the fuel system would have been avoided, and a left-wing heavy fuel imbalance would not have developed.

5. If the pilot had performed a complete preflight inspection before the flight to Oroville Municipal Airport, he would have had an opportunity to detect whether ice crystals or water were present in the fuel and determine whether the fuel filter bypass indicator was extended, which could have explained the reason for the fuel boost pump advisories annunciated during the preceding flight.

6. About 1 hour 21 minutes into the flight, the fuel supplied to the airplane's engine was being drawn solely from the right fuel tank by the right fuel boost pump, and the left-wing-heavy fuel imbalance continued to increase.

7. The left and right fuel tanks were equally receiving fuel through the fuel return lines, but the left-wing-heavy fuel imbalance continued to increase during the flight because fuel was only being drawn from the right fuel tank.

8. The fuel system continued to provide fuel to the engine throughout the flight, even with the low fuel pressure state and the degraded performance of the left-side fuel system.

9. Although the pilot should have diverted to land the airplane as soon as practical after his attempt to restore fuel balance within the maximum imbalance limitation was unsuccessful, his eventual decision to divert to Bert Mooney Airport likely resulted from his recognition of the magnitude of the increasing left-wing-heavy fuel imbalance situation.

10. The airplane was controllable in static flight with the left-wing-heavy fuel imbalance that existed at the time of the accident, but the pilot lost control of the airplane with the dynamic maneuvers during the final moments of the flight.

11. The large left rolling moment induced by the left-wing-heavy fuel imbalance could have been minimized or even avoided if the pilot had followed Pilatus Aircraft's required procedures for flight operations with a fuel imbalance.

12. If the pilot had diverted earlier in the flight to one of several suitable airports along the airplane's route of flight, the outcome of this flight would likely have been different because the airplane would have had a less severe fuel imbalance and the pilot would not have had to contend with the airplane's deteriorating performance as the imbalance steadily progressed.

13. The pilot underestimated the seriousness of the initial fuel imbalance indications because he had not experienced any adverse outcomes from ignoring similar indications during previous flights.

14. The safety hazard involving fuel system ice accumulation could be mitigated if fuel filler placards installed aboard aircraft requiring a fuel system icing inhibitor specified that requirement.

15. Federal Aviation Administration pilot and operator guidance on the use of fuel system icing inhibitors would help raise awareness of the need to include this additive in turbine engine-powered aircraft fuel systems that require the additive.

16. At least four of the seven children on board the airplane were not restrained or were improperly restrained.

17. Although the number of passengers on board the airplane during the final flight leg did not comply with the PC-12 airplane flight manual limitation requiring no more than nine passengers, the four additional passengers on board the airplane did not directly affect the outcome of the accident.

18. For survivable accidents, passengers aboard airplanes operating under 14 *Code of Federal Regulations* Part 91 would be afforded better crash protection if each seat and restraint system were limited to only one passenger and children less than 2 years of age were restrained in an approved child restraint system.

19. Although the download of nonvolatile memory data provided key information in determining the circumstances that led to this accident, a flight recorder system that captured cockpit audio, images, and parametric data would have provided additional information about the accident that was not possible to determine from the downloaded nonvolatile memory data.

3.2 Probable Cause

The National Transportation Safety Board determines that the probable cause of this accident was (1) the pilot's failure to ensure that a fuel system icing inhibitor was added to the fuel before the flights on the day of the accident; (2) his failure to take appropriate remedial actions after a low fuel pressure state (resulting from icing within the fuel system) and a lateral fuel imbalance developed, including diverting to a suitable airport before the fuel imbalance became extreme; and (3) a loss of control while the pilot was maneuvering the left-wing-heavy airplane near the approach end of the runway.

4. Recommendations

4.1 New Recommendations

As a result of this investigation, the National Transportation Safety Board makes the following recommendations to the Federal Aviation Administration:

> Amend certification requirements for aircraft requiring fuel additives, including fuel system icing inhibitors, so that those limitations are highlighted by a warning in the limitations section of the airplane flight manual. (A-11-70)

> Require all existing certificated aircraft (both newly manufactured and in-service aircraft) that require fuel additives, including fuel system icing inhibitors, to have those limitations highlighted by a warning in the limitations section of the airplane flight manual. (A-11-71)

> Amend aircraft certification fuel placarding requirements so that aircraft requiring fuel additives, including fuel system icing inhibitors, have a fuel filler placard that notes this limitation and refers to the airplane flight manual for specific information about the limitation. (A-11-72)

> Require all existing certificated aircraft (both newly manufactured and in-service aircraft) that require fuel additives, including fuel system icing inhibitors, to have a fuel filler placard that notes this limitation and refers to the airplane flight manual for specific information about the limitation. (A-11-73)

> Issue guidance on fuel system icing prevention that (1) includes pilot precautions and procedures to avoid fuel system icing problems aboard turbine engine-powered aircraft and (2) describes the possible consequences of failing to use a fuel system icing inhibitor, if required by the airplane flight manual, especially during operations at high altitudes and in cold temperatures. (A-11-74)

As a result of this investigation, the National Transportation Safety Board makes the following recommendations to the European Aviation Safety Agency:

> Amend certification requirements for aircraft requiring fuel additives, including fuel system icing inhibitors, so that those limitations are highlighted by a warning in the limitations section of the airplane flight manual. (A-11-75)

> Require all existing certificated aircraft (both newly manufactured and in-service aircraft) that require fuel additives, including fuel system icing inhibitors, to have those limitations highlighted by a warning in the limitations section of the airplane flight manual. (A-11-76)

> Amend aircraft certification fuel placarding requirements so that aircraft requiring fuel additives, including fuel system icing inhibitors, have a fuel filler placard that

notes this limitation and refers to the airplane flight manual for specific information about the limitation. (A-11-77)

Require all existing certificated aircraft (both newly manufactured and in-service aircraft) that require fuel additives, including fuel system icing inhibitors, to have a fuel filler placard that notes this limitation and refers to the airplane flight manual for specific information about the limitation. (A-11-78)

4.2 Previously Issued Recommendations Resulting From This Accident Investigation

The National Transportation Safety Board issued the following recommendations to the Federal Aviation Administration on August 11, 2010:

Amend 14 *Code of Federal Regulations* Part 91 to require separate seats and restraints for every occupant. (A-10-121)

Amend 14 *Code of Federal Regulations* Part 91 to require each person who is less than 2 years of age to be restrained in a separate seat position by an appropriate child restraint system during takeoff, landing, and turbulence. (A-10-122)

The National Transportation Safety Board issued the following recommendation to the Federal Aviation Administration on March 18, 2010:

Establish and implement standard procedures to document and share control information, such as frequency changes, contact with pilots, and the confirmation of the receipt of weather information, at air traffic control facilities that do not currently have such a procedure. These procedures should provide visual communication of at least the control information that would be communicated by the marking and posting of paper flight-progress strips described in Federal Aviation Administration Order 7110.65, "Air Traffic Control." (A-10-42)

4.3 Previously Issued Recommendation Classified in This Report

Safety Recommendations A-10-121, which was issued to the Federal Aviation Administration on August 11, 2010, is reclassified "Open—Unacceptable Response" in section 2.5 of this report.

Amend 14 *Code of Federal Regulations* Part 91 to require separate seats and restraints for every occupant.

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

DEBORAH A.P. HERSMAN
Chairman

ROBERT L. SUMWALT
Member

CHRISTOPHER A. HART
Vice Chairman

MARK R. ROSEKIND
Member

EARL F. WEENER
Member

Adopted: July 12, 2011

BY THE NATIONAL TRANSPORTATION SAFETY BOARD

JENNIFER HOMENDY
Chair

MICHAEL GRAHAM
Member

BRUCE LANDSBERG
Vice Chairman

THOMAS CHAPMAN
Member

Revised: April 17, 2023

5. Appendix

Investigation and Public Hearing

Investigation

The National Transportation Safety Board (NTSB) was notified of this accident at 1500 on March 22, 2009. Investigators from the NTSB's Western Pacific Region office arrived on scene starting at 1600, and a go-team from NTSB headquarters and the NTSB's Eastern Region office arrived in Butte at 0300 on March 23. Accompanying the team in Butte was former Acting Chairman Mark Rosenker.

The following investigative teams were formed: Operations, Airworthiness, and Air Traffic Control. Specialists in the areas of survival factors and aircraft performance were also assigned to the investigation. In addition, a specialist was assigned to compile witness statements.

Parties to the investigation were the Federal Aviation Administration, Crane Aerospace, and Hartzell Propeller. In accordance with the provisions of Annex 13 to the Convention on International Civil Aviation, the Aircraft Accident Investigation Bureau of Switzerland participated in the investigation as the representative of the State of Design and Manufacture (Airframe), and the Transportation Safety Board of Canada (TSB) participated in the investigation as the representative of the State of Design and Manufacture (Powerplants). The European Aviation Safety Agency and Pilatus Aircraft participated in the investigation as technical advisors to the Aircraft Accident Investigation Bureau of Switzerland, and Pratt & Whitney Canada participated in the investigation as a technical advisor to the TSB, as provided for in Annex 13.

Public Hearing

No public hearing was held for this accident.