Transportation Safety Board of Canada

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AVIATION INVESTIGATION REPORT A15C0134

INCORRECT FUEL TYPE AND FORCED LANDING
KEYSTONE AIR SERVICE LTD.
PIPER PA-31-350, C-FXLO
THOMPSON, MANITOBA, 1 NM SW
15 SEPTEMBER 2015

Canada

Transportation Safety Board of Canada
Place du Centre
200 Promenade du Portage, 4th floor
Gatineau QC K1A 1K8
819-994-3741
1-800-387-3557
www.tsb.gc.ca
communications@bst-tsb.gc.ca

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Summary

At 1817 Central Daylight Time, the Keystone Air Service Ltd. Piper PA-31-350 (registration C-FXLO, serial number 31-8052022) departed Runway 06 at Thompson Airport, Manitoba, on an instrument flight rules flight to Winnipeg/James Armstrong Richardson International Airport, Manitoba, with 2 pilots and 6 passengers on board. Shortly after rotation, both engines began to lose power. The crew attempted to return to the airport, but the aircraft was unable to maintain altitude. The landing gear was extended in preparation for a forced landing on a highway southwest of the airport. Due to oncoming traffic, the forced landing was conducted in a forested area adjacent to the highway, approximately 700 metres south of the threshold of Runway 06. The occupants sustained varying serious injuries but were able to assist each other and exit the aircraft. The emergency locator transmitter activated, and there was no fire. Emergency services were activated by a 911 call and by the Thompson flight service station. Initial assistance was provided by sheriffs of the Manitoba Department of Justice after a crew member flagged down their vehicle on the highway.

Le présent rapport est également disponible en français.

Factual information

History of the flight

The flight crew and passengers of the Keystone Air Service Ltd. (Keystone) Piper PA-31-350 (registration C-FXLO, serial number 31-8052022) operating as flight KEE208 had departed Winnipeg/James Armstrong Richardson International Airport (CYWG) at 0819[1] for a series of flights to several northern Manitoba communities. A passenger safety briefing was carried out by the second-in-command (SIC) pilot, and abbreviated briefings were performed at each stop throughout the day. The last 2 planned stops were the Oxford House Airport (CYOH) and the Pikwitonei Airport (CZMN). During the stopover at CYOH, the crew evaluated the weather conditions at CZMN, determined that the flight could not be conducted under visual flight rules, and cancelled that leg of the trip. After further determining that an instrument flight rules flight to CYWG with suitable alternates would require additional fuel, the crew decided to proceed to the Thompson Airport (CYTH), Manitoba, approximately 102 nautical miles (nm) from CYOH, to refuel. Keystone flight-following personnel were contacted by telephone and instructed to alert the fuel dealer in CYTH. However, it is uncertain whether the aircraft fuel handling technician (AFHT) received a call from Keystone. KEE208 departed from CYOH at 1640.

Prior to the arrival of KEE208, the AFHT in CYTH fuelled an aircraft with Jet-A1 fuel and returned in the fuel truck (Photo 1) to the fuel dealer's office. The AFHT parked the Jet-A1 fuel truck outside the office, left it running, and entered the building.

Photo 1. Jet-A1 truck

It was raining steadily at CYTH when KEE208 arrived at 1728. While KEE208 was taxiing to the apron, the AFHT exited the building and drove the Jet-A1 truck to meet the aircraft,

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1 All times are Central Daylight Time (Coordinated Universal Time minus 5 hours).

unaware of what type or amount of fuel would be required. The AFHT parked the Jet-A1 truck in front of KEE208 with the left side of the truck facing the aircraft.

The pilot-in-command (PIC), who was performing shutdown checks, observed the red-and-white truck in front of the aircraft as the last engine was being shut down. The PIC intended to relay the fuel load to the AFHT, and instructed the SIC to chock the aircraft and escort the passengers to the terminal.

The SIC exited the aircraft and escorted the passengers to the left wingtip area, instructing them to wait while a chock was placed under the nosewheel. The SIC did not look at the placards on the truck, but noticed that the AFHT was having difficulty determining which fuel filler openings were for the main tanks. The SIC identified each fuel filler opening and instructed the AFHT to fill the main fuel tanks and put 80 litres in each auxiliary tank. Then the SIC escorted the passengers to the airport terminal through the fuel dealer's building via the air-side door that is normally accessible to flight crews. The PIC had observed and heard the SIC talking to the AFHT and did not speak to the AFHT regarding fuel load. The PIC performed post-flight duties, then exited the aircraft at 1734 and went to the fuel dealer's building. The PIC informed a person behind the counter inside the building that someone would return to sign the fuel slip by 1800.

The AFHT did not see the fuel-type placards adjacent to the aircraft filler openings, but noted that the Jet-A1 flared spout[2] did not fit into the aircraft's fuel filler opening (Photo 2). The AFHT removed the Jet-A1 flared spout and replaced it with a reduced-diameter spout (Photo 3).[3] The aircraft was fuelled with 406 litres of Jet-A1, distributed among all 4 tanks. After the fuelling was completed, the Jet-A1 flared spout was re-installed. The AFHT printed a fuel slip and recorded the removal and re-installation of the Jet-A1 flared spout in the fuel truck's Depleting Inventory Log. The AFHT drove back to the fuel dealer building, parked, and shut down the truck.

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2 Also referred to as a "selective nozzle spout," "jet nozzle," and "jet fuel spout" in Imperial Oil manuals.

3 Also referred to as a "non-selective spout" or "non-selective nozzle" in Imperial Oil manuals.

Photo 2. Placard and fuel filler opening

Photo 3. Exemplar flared spout (left) and reduced-diameter (brass) spout

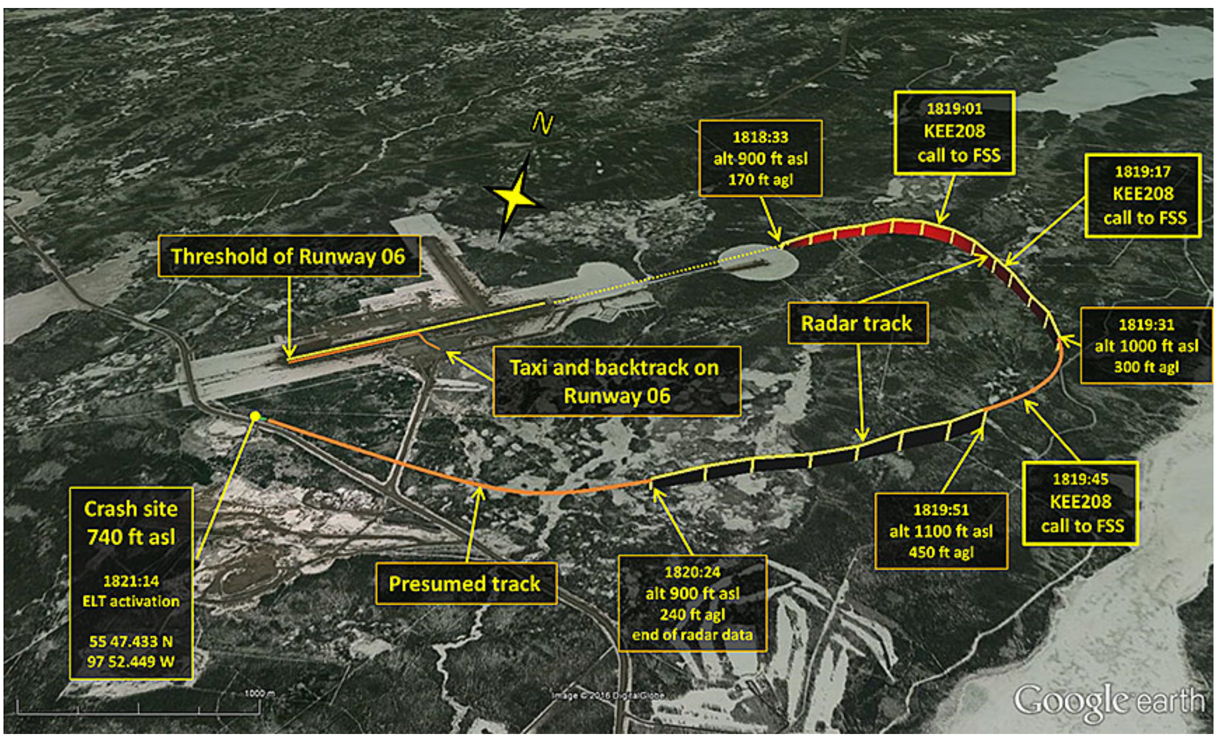
At 1800, the PIC returned to the fuel dealer's building, but was unable to gain entry through the secured ground-side door to retrieve the fuel slip. The lights were off and the PIC could not see a fuel slip on the counter. The PIC returned to the airport terminal. The crew and passengers exited the terminal's air-side door, returned to the aircraft, and prepared to depart. Neither the PIC nor the SIC attempted to access the fuel dealer's building through the air-side door. The SIC checked the fuel caps and removed the wheel chock. An abbreviated safety briefing was performed by the SIC, and all of the occupants fastened their seat belts, which remained securely fastened during the occurrence flight. The pilots donned shoulder harnesses in addition to their lap belts. The pre-flight checks were completed; however, the fuel sumps were not sampled. The engines were started at 1813, and the crew obtained their instrument flight rules clearance, which would expire at 1819. Due to expected inbound traffic, the taxi to Runway 06 was expedited, and the take-off roll commenced at 1817 (Figure 1).

The SIC performed the take-off from the right-hand seat, during which the engines (Lycoming TIO 540 J2B and LTIO 540 J2B) appeared to perform normally. After rotation, the aircraft was not accelerating or climbing as expected, and the manifold pressure of both engines had decreased. The crew selected the landing gear up and retracted the flaps. The SIC initiated a gentle turn to the right and concentrated on maintaining airspeed while the PIC attempted to troubleshoot the power loss.

At 1819:01, the PIC made a radio call to the CYTH flight service station (FSS) advising that they were commencing a right turn to come back for a landing on Runway 06. The aircraft was unable to climb higher than approximately 400 feet above ground level (agl).

At 1819:17, the PIC advised FSS that KEE208 was going to turn downwind for Runway 06. The crew had the airport in sight while the aircraft was on the downwind leg at 1819:45. The power output of both engines decreased further, and the aircraft began to descend. The PIC instructed the SIC to perform a forced landing on Highway 391, and moved the landing gear selector to the down position. The PIC subsequently observed oncoming traffic on the highway and took over control of the aircraft. The PIC turned the aircraft to the right and conducted a forced landing, under control, into a partially cleared wooded area approximately 50 metres north of, and parallel to, the highway. The cabin door was forced open during the initial impact with the ground. The aircraft came to rest near the end of the partially clear area. Its emergency locator transmitter (ELT) activated at 1821:14. Repeated attempts by FSS to contact KEE208 were unsuccessful.

Figure 1. Aerial view of Thompson Airport, showing the flight path of KEE208 as plotted by radar (Source: Google Earth, with annotations by TSB)



Thompson meteorological information

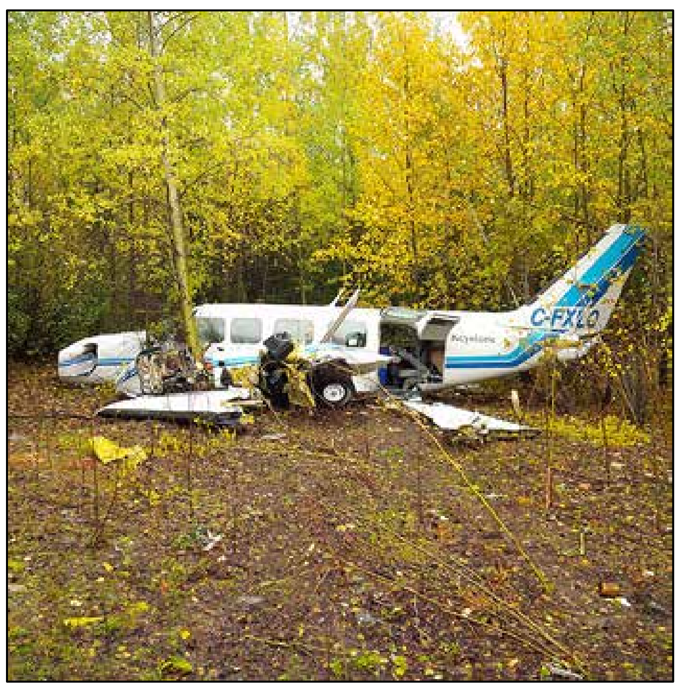
Table 1. Thompson meteorological information

Time	1700	1800	1833
Type of weather statement	Routine aviation weather report (METAR)	METAR	Special weather report (SPECI)
Wind direction (° true)	050	050	050
Wind speed (knots)	12 gusting to 19	11 gusting to 16	9 gusting to 17
Visibility (statute miles)	7	7	6
Precipitation	Light rain	Light rain	Light rain
Cloud layers (feet agl)	500 scattered 700 broken 900 overcast	400 few 600 broken 900 overcast	400 few 600 broken 900 overcast
Temperature (°C)	9	9	9
Dew point (°C)	8	8	9
Altimeter setting (in Hg)	29.88	29.88	29.86

Aircraft wreckage information

The descent angle through the trees to the impact point of the main landing gear was about a 10° descent angle in a nose-high, wings-level attitude. From the initial impact point, the aircraft travelled another 30 m before coming to a stop. The total length of the wreckage trail from the first tree impact was approximately 76 m. The crash site was a partial clearing strewn with rocks, debris, and scrap metal, indicating that the area was likely an old dump site.

Photo 4. Accident site



Both of the aircraft's horizontal stabilizers had broken away. The wings were torn off outboard of both engine nacelles. The wing flaps were up and the landing gear was down at impact. The nose landing gear fork and wheel assembly had broken away, and the remaining portion of the nose landing gear leg had been forced back into the wheel bay by the impact. The left main landing gear oleo strut was bent back by 90°. The right main landing gear leg had partially collapsed. The aircraft battery box was lying on the ground about 6 m ahead of its mounting structure on the front bulkhead of the fuselage.

The left engine remained attached only by wires and cables. The right engine was still marginally attached to the firewall; however, several tubes of the engine mount were broken. The spark plugs and piston crowns that were examined exhibited a clean, shot-blasted appearance. The propellers sustained limited rotational damage; however, there was severe bending and twisting damage to all blades.

All 4 fuel cells had ruptured, dispersing fuel along the wreckage trail. There was an odour of jet fuel throughout the crash site. The aircraft's fuel caps were in place, and the filler openings were approximately 2.3 inches in diameter. There was sufficient fuel remaining in the right fuel filter bowl and the left auxiliary fuel cell to obtain samples.

Survivability

The aircraft was fitted with shoulder harnesses and lap belts for the crew. The PIC's seat was intact and secured to the floor track. The SIC's seat was attached to the floor track, but the seat pan had collapsed.

There were a total of 6 passenger seats installed in 3 rows. Each passenger seat was fitted with a lap belt, and all except the third row were fitted with headrests. Except for the first- and second-row seats on the left side of the cabin, the seat pans of all of the passenger seats had collapsed to some degree. The cabin floor and seat track on the right side had deflected down during the crash.

The first-row passenger seats faced aft. This arrangement placed the seatbacks toward the cockpit bulkhead. The seatbacks of the first row of passenger seats had been forced forward against the cockpit bulkhead, which in turn had partially broken loose. The inboard legs of the second-row seat on the right had collapsed, and its forward leg was detached from the track. The bottom cushion and seat pan of the third-row seat on the right had broken free from its piano-hinge mounting, and its inboard side had twisted forward.

Aircraft information

The Piper PA-31-350 is a twin-engine aircraft certified for day and night visual flight rules and instrument flight rules operations. It is equipped with reciprocating engines that require aviation gasoline (AVGAS) with a minimum 100 octane rating.

A placard is required to be installed on the wing surface near each fuel filler opening specifying the fuel type and minimum grade required.[4] On the occurrence aircraft, adjacent to 3 of the fuel filler openings, was a placard that specified the aircraft's fuel type and grade as well as its fuel capacity (Photo 2). The placard adjacent to the left-main fuel filler opening

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[4] Piper Aircraft Corp. PA-31-350 *Pilot Operating Handbook*, section 2, 2.29 Placards.

specified the grade and capacity only. All of the placards had black text on a white background.

Testing of the samples obtained from the wreckage was performed under the direction of the TSB Laboratory. Test results indicated that the samples consisted of about 32% AVGAS, while the remaining 68% was a heavier hydrocarbon consistent with the properties of Jet-A1 fuel.

Fuel is stored in 4 flexible fuel cells (2 in each wing). The outboard (auxiliary) cells hold 40 U.S. gallons each, and the inboard (main) cells hold 56 U.S. gallons each, of which a total of 182 gallons are usable.

Drain valves for taking fuel samples are located at the fuel-cell sumps (4 valves), the fuel filter bowls (2 valves), and the lowest part of the crossfeed system (1 valve). Sampling of the drains for water, sediment, and proper fuel are part of the pre-flight check.[5] The Keystone PA31 *Standard Operating Procedures* (SOPs) state, "The 'Exterior Pre-Flight' (external inspection) […] shall be completed on the first flight of the day or whenever the aircraft has been completely de-powered and left unattended."[6] It was normal practice for Keystone flight crews to sample the fuel drains prior to the first flight of the day, but not after subsequent fuellings.

Piper Service Bulletin 797A, issued on 02 April 1985, required the installation of reduced-diameter fuel filler openings to prevent misfuelling. The service bulletin was revised to include instructions that were to be followed in the event that jet fuel was introduced into a piston engine aircraft. Service Bulletin 797B became mandatory with the issue of U.S. Federal Aviation Administration (FAA) Airworthiness Directive (AD) 87-21-01, effective 02 November 1987. The aircraft was in compliance with this directive.

A TSB review of the Operational Flight Plan/Load Control document prepared by the crew for KEE208 indicated that the centre of gravity and take-off weight of the aircraft were within acceptable limits. The aircraft had undergone a scheduled inspection approximately 82 flight hours prior to the occurrence. A review of maintenance records indicated that the aircraft was maintained in accordance with existing regulations and standards. There were no reported defects prior to the occurrence flight.

Crew information

Records indicate that the flight crew was certified and qualified for the flight in accordance with existing regulations. The PIC held an Airline Transport Pilot licence and a Category 1 medical certificate with a limitation that glasses must be worn. The PIC was wearing glasses during the occurrence flight. The PIC had approximately 2000 total flight hours, including about 1000 flight hours on the PA-31-350. During the 7 days prior to the occurrence, the PIC

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5 Piper Aircraft Corp. PA-31-350 *Pilot Operating Handbook*, section 4, 4.5 Pre-flight Check.

6 Keystone Air Service Ltd., PA31 Standard Operating Procedures, section 3, 3.6.6 Pre-flight inspections and checks.

had accumulated 34.8 flight duty hours and a flight time of 14.4 hours. The PIC had arrived at the hangar at approximately 0630, had been on duty for approximately 11.75 hours, and had been awake for approximately 12.75 hours when the occurrence took place.

The PIC occupied the left seat. The PIC was the pilot monitoring for the initial portion of the flight, and became the pilot flying shortly before the forced landing.

The SIC held a commercial pilot licence and a Category 1 medical certificate. The SIC had approximately 446 total flight hours, including about 120 flight hours on the PA-31-350. During the 7 days prior to the occurrence, the SIC had accumulated 21.9 flight duty hours and a flight time of 9.6 hours. The SIC had arrived at the hangar at approximately 0630, had been on duty for approximately 11.75 hours, and had been awake for approximately 13.75 hours when the occurrence took place.

A fatigue analysis of the PIC and SIC was conducted. It was concluded that it was unlikely that they were experiencing sleep-related fatigue.

On previous occasions, both crew members had flown into CYTH and obtained fuel from the fuel dealer. The normal practice of the PIC was to scrutinize fuel slips and then e-mail a photograph of the slip to Keystone.

Thompson Airport fuel dealer

The Esso fuel dealer at Thompson Airport (CYTH) was Mara-Tech Aviation Fuels Ltd. (Mara-Tech), which operated the Imperial Oil (Imperial) owned facility and equipment under an aviation dealer agreement. In addition to its day-to-day operation of the facility, Mara-Tech was responsible for staffing the facility and training the employees. Training materials were supplied by Imperial and consisted of a series of CDs or VHS tapes whose content was organized into modules. Each module was accompanied by a corresponding multiple-choice quiz.

Aviation dealer agreements require that fuel dealers adhere to Imperial's operating standards and procedures. Under the aviation dealer agreement, fuel dealers have a licence to use Imperial brand trademarks, such as Esso and Esso Aviation, in marketing their businesses.

Aircraft fuel handling technician

The manager of Mara-Tech's Thompson facility hired the AFHT, and training began on 06 August 2015. The AFHT had no previous aviation experience and, consequently, no prior knowledge of aircraft types and their respective details, such as the locations of fuel filler openings and fuel type requirements.

The AFHT's training consisted of reading the Imperial training material, viewing the CDs, and completing the corresponding multiple-choice quizzes. Additional certifications, such as Airside Vehicle Operator's Permit and Transportation of Dangerous Goods, were administered by the manager at Mara-Tech's Thompson facility. The AFHT received Mara-

Tech's Aviation Fuel Handling Training certificate on 10 August 2015. The AFHT also underwent on-the-job training that consisted of riding along with the manager to gain experience fuelling aircraft. The AFHT carried out the first unassisted fuelling on 22 August 2015. The majority of the aircraft that the AFHT serviced required Jet-A1 fuel. However, given the various types of aircraft, it was sometimes necessary to remove the Jet-A1 flared spout and install the reduced-diameter spout.

Aircraft fuelling

Transport Canada Civil Aviation (Transport Canada [TC]) does not regulate or perform oversight of fuel dealers. However, the subject of TC's *Aerodrome Safety Circular* (ASC) 2006-029[7] is "Storage, Handling and Dispensing of Aviation Fuels at Aerodromes," which provides information and guidance to those involved with the fuelling of aircraft at aerodromes. The current version of this document is *Advisory Circular* (AC) 300-012, issued 01 October 2014. It restates TC's position regarding the third edition of Canadian Standards Association (CSA) standard B836-14, titled *Storage, handling, and dispensing of aviation fuels at aerodromes*. According to AC 300-012,

> It is Transport Canada's view that CSA B836-14 provides industry the best practices. Since the introduction of this standard, Transport Canada also recommended that all aerodrome operators adopt the standard for their individual operations.[8]

Standard B836-14 "specifies the minimum design, construction, operation, maintenance, and emergency response requirements for the storage, handling, and dispensing of aviation fuels at aerodromes."[9] The standard establishes training of personnel and preparation of an operations manual.

Accordingly, Imperial provides the *Aviation Operation Standards Manual* (AOSM): *Dealer Airport Procedures* and the companion *Quick Reference Guide* to its licensed fuel dealers. The AOSM contains standards and procedures for fuel dealers and comprises a number of documents, each addressing a specific aspect of an airport fuelling operation.

Document ADD-P-Z605 (605), titled *Overwing Fuelling*, is divided into 6 sections. The actual procedure for delivery of fuel to an aircraft is detailed in table format in sections 2 to 5, with columns labelled "Step [number]," "Procedure," "Explanations," "Hazards," and "Actions." Procedures concerning verification of the fuel grade, excerpted[10] from sections 2 to 5, read as follows:

Section 2. Order taking

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7 Transport Canada, Aerodrome Safety Circular ASC 2006-029, Issue 01 (effective 24 May 2006), replaced by Transport Canada Advisory Circular AC300-012 (effective 10 November 2015).

8 Transport Canada, Advisory Circular AC300-012, 3.0 Background (2).

9 Canadian Standards Association (CSA) Standard B836-14, 1. Scope, 1.1.

10 ExxonMobil Aviation, ADD-P-Z605, *Overwing Fuelling* (June 2011).

- Step 1: "Take order and repeat back to customer for confirmation."
- Step 2: "All fuel orders should be recorded on a Refuelling Order Running Sheet."

Section 3. Grade confirmation

- Step 1: "Fuel Order Form completion or reference to Standing Fuel Order List."
- Step 2: "Upon arrival at the aircraft physically confirm grade by comparing Nozzle Grade Tag with Wing Tank Decal."
- Step 3: "Use of Selective Nozzle Spout." [This step contains a detailed explanation of the use of the spout and identifies the hazard as "Delivery of incorrect grade into aircraft."]

Section 4. Arrival and delivery

- Step 13: "Compare Nozzle Grade Identification Tag with Aircraft Wing Tank Decal."

Section 5. Equipment stowage and departure

- Step 2: "Completion of Documentation."
    - "Ensure delivery docket [fuel slip] signed unless standing fuel order in place."

The investigation revealed that the AFHTs at Mara-Tech's Thompson facility rarely used the fuel order form. The fuel dealer routinely fuelled aircraft operated by several different companies. A review of fuel slips from the week prior to the occurrence showed that about 6% of them had been signed by a member of a flight crew.

Fuelling personnel were required to remain current on issues of the *Operations Focus Letter*, published periodically by Imperial. Misfuelling of aircraft was a topic in each of the letters. Imperial also produced 2 issues of the *Aviation Technical Bulletin* (AVTec) that addressed misfuelling issues. AVTec 13.08, released in August 2013, reviewed over-wing fuelling procedures and introduced documents that were available on an Imperial website. AVTec 15.01, released in February 2015, featured a case study of a misfuelling event followed by a reiteration of the procedures that are intended to prevent such occurrences.

Imperial also produces a document called *Toolbox Talk*. An issue titled *Misfuelling Awareness* (ADD-T-Z133) is an 8-page treatise aimed at raising awareness of, and preventing, misfuelling events. The document is in slide show format and is summarized in a wall poster published in July 2013 and supplied to fuel dealers (Appendix A). The poster was displayed on the wall of the fuel dealer's office, but was partially obscured by other documents.

Misfuelling was identified as a medium-level residual risk in a site level risk assessment (SLRA) that Imperial carried out in September 2011. The SLRA determined that the risk of "delivery of incorrect fuel grade to aircraft" required an upgrade to the Thompson fuel dealer's site contingency plan.

The bulletins, letters, and site contingency plan were reviewed by investigators; each of those documents was accompanied by a sign-off sheet bearing the AFHT's signature.

An update to the site contingency plan was issued in June 2012. It identified the following steps to be taken in the event of an incorrectly fuelled aircraft:

> 1. IMMEDIATELY notify the customer/pilot(s)
> 2. Leave your vehicle in front of the affected aircraft
> 3. Call the supervisor
> 4. Assist the customer/pilot with defueling/anything they might need help with
> 5. Make sure an AME (plane mechanic) signs off before the aircraft departs
>
> AvGas in a Jet-A1 plane might be ok (pilot will advise), but Jet fuel in an Avgas plane is a ***NO GO***[11]

Following the SLRA, an inspection of Mara-Tech's Thompson facility was performed by 2 Imperial team members in May 2014. These members witnessed several over-wing fuelling operations being conducted in accordance with AOSM procedures.

The Keystone *Company Operations Manual* (COM) states, "Pilots usually fuel the aircraft themselves. However, when a third party provides fuelling services pilots shall supervise the fuelling of their aeroplanes to ensure that fuelling requirements are met."[12]

Additionally, the Keystone PA-31 SOPs state:

> The PIC is responsible for close supervision of all details of aircraft refuelling when being performed by other than authorized company employees or representative of the company. Unless on base, one crew member must be present during refuelling who will be responsible for the type, condition and amount of fuel boarded.[13]

During the course of the investigation, it became apparent that, despite the directives provided in the COM and SOPs, supervision of fuelling was not performed consistently among Keystone pilots. The degree of supervision appeared to vary based on the levels of trust that individual pilots placed in the fuel dealers at Keystone's various destinations. For example, a fuel dealer at a major centre tended to be trusted more, and supervised less, than a fuel dealer at a smaller airport. Some pilots regularly performed some level of supervision, while others were rarely present at the aircraft during fuelling.

Inattentional blindness

When mentally occupied with a task or otherwise absorbed in thought, an individual may look toward an object or event, yet not notice or register it in consciousness.[14] This phenomenon, called inattentional blindness,[15] occurs when people mistakenly filter out

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11 Imperial, Delivery of incorrect fuel procedures (28 June 2012).

12 Keystone Air Service Ltd., Company Operations Manual, section 4.12.6 *Supervision of Fuelling*.

13 Keystone Air Service Ltd., PA31 Standard Operating Procedures, 3.25 *Aircraft fuelling*, 3.25.1 General.

14 V. Beanland and K. Pammer, "Looking without seeing or seeing without looking? Eye movements in sustained inattentional blindness," *Vision Research* Vol. 50, Issue 10 (2010), pp. 977–988.

15 A. Mack and I. Rock, *Inattentional Blindness* (MIT Press, 1998).

important information that is available to the senses. Through inattentional blindness, a pilot's engagement in one task can result in the pilot missing—or being "blind" to—a second, simultaneous event.

Misfuelling history

In a discussion of operational engine failures caused by misfuelling accidents, FAA AC 20-105B states, "Reciprocating [*gasoline*] engines that burn Jet A at high power settings suffer detonations, rapid loss of power, and high cylinder head temperatures, quickly followed by complete engine failure."[16]

Following a series of misfuelling events in the 1980s, the aviation industry took initiatives to prevent further occurrences. Some aircraft manufacturers issued service bulletins, and made kits available, to reduce the size of fuel filler openings on aircraft that required AVGAS. The FAA and TC subsequently issued airworthiness directives that made the service bulletins mandatory.

As a result, flared spouts that would not fit into the smaller AVGAS filler openings were introduced on fuelling equipment. Fuel suppliers placed additional labelling and placarding on fuelling equipment. AFHT training programs were introduced, and more detailed operations manuals were developed. FAA AC 20-105B and bulletins issued by some aircraft manufacturers encouraged operators to remove the words "Turbo" and "Turbo-charged" from the cowlings of turbo-charged aircraft. Misfuelling was also a topic in a TC *Notice to Aircraft Maintenance Engineers and Aircraft Owners*[17] and several issues of its *Aviation Safety Letter* (ASL).[18]

In 1993, size standards for fuel filler openings were incorporated in *Federal Aviation Regulations* (FARs) Part 23 Airworthiness Standards: Normal, Utility, Acrobatic and Commuter Category Airplanes.[19] The standards specified that airplanes with engines that require gasoline must have fuel filler openings no larger than 2.36 inches; airplanes with turbine engines must have fuel filler openings no smaller than 2.95 inches; and each fuel filler opening must be marked with the fuel type and minimum grade.[20] Canada adopted identical airworthiness standards in *Part V -Airworthiness Manual Chapter 523- Normal, Utility, Aerobatic and Commuter Category Aeroplanes* (523.973 and 523.1557). The FAA and TC airworthiness standards for rotorcraft do not specify the size of fuel filler openings.

Certain airplanes and rotorcraft powered by turbine engines cannot be fuelled using the Jet-A1 flared spout. Some aircraft manufactured prior to the current standard have fuel filler

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[16] Federal Aviation Administration, Advisory Circular AC 20-105B, *Reciprocating Engine Power-Loss Accident Prevention and Trend Monitoring* (15 June 1998), 4.d.(1).

[17] Transport Canada, *Notice to Aircraft Maintenance Engineers and Aircraft Owners* 10/85.

[18] Transport Canada, Aviation Safety Letter, ASLs 2/91, 6/92, 2/2001, and 4/2011.

[19] *Federal Aviation Regulations* (FARs) 23.973, Fuel Tank Filler Connection.

[20] *Federal Aviation Regulations* (FARs) 23.1557, Miscellaneous markings and placards, (c) Fuel and oil filler openings.

openings that do not meet the current dimension requirements. Aircraft that have been modified by replacing the reciprocating engine with a turbine engine sometimes retain their original fuel filler openings. The angle and location of the fuel filler openings on some aircraft make the use of the Jet-A1 flared spout impractical. Consequently, many Jet-A1 fuel trucks and stationary fuelling cabinets are equipped with a reduced-diameter spout that can be temporarily installed in place of the Jet-A1 flared spout.

A review of the TSB database revealed that, since 1980, there have been 21 recorded instances in which jet fuel was delivered to an aircraft instead of AVGAS, 10 of which have occurred since 2000 (Appendix B). Of those 21 events, 17 occurred at an aerodrome, 3 were related to refuelling from drums, and 1 occurred at a float-plane dock. These misfuelling events resulted in 8 crashes and 11 forced landings. There was 1 fatality and a number of injuries, some severe. In 2 cases, the misfuelling was detected prior to departure of the aircraft.

TSB laboratory reports

The TSB completed the following laboratory reports in support of this investigation:

- LP230/2015 Analysis of Fuel Samples
- LP286/2015 Radar Data Analysis

Analysis

Both pilots were certified and qualified for the flight. A flight crew fatigue analysis indicated that it was unlikely that sleep-related fatigue was a factor in the occurrence. The aircraft was maintained in accordance with existing regulations, and no defects had been reported prior to the occurrence flight. Examination of the wreckage did not reveal any pre-existing defects that may have contributed to the accident. Damage sustained by the propellers indicated that the engines were not producing significant power at impact. Early in the investigation, it became apparent that the aircraft had been incorrectly fuelled with Jet-A1 instead of AVGAS. The weather conditions at the time of the occurrence were not considered to be a major factor. The analysis will focus on survival aspects of the crash and the delivery of the incorrect fuel type.

Survivability

The planned landing on the highway had to be abandoned due to approaching traffic. The aircraft was flown into the trees, under control, on an approximately 10° descent angle in a nose-high, wings-level attitude. A great deal of energy was dissipated by the tearing away of the wings as well as the deformation and collapse of the extended landing gear.

The fuselage remained upright, and the cabin provided a survivable volume. The fuselage was distorted during the initial impact with the ground, and the distortion forced the cabin door open. However, the occupants were able to remain in the cabin during the accident sequence, because all of the available seat belts were used. The distortion also affected the cabin floor and resulted in the release of several seat legs from their attachment points. Some seat pans had partially collapsed while absorbing energy during the initial impact. The use of all of the available restraint systems in the aircraft contributed to the survival of the occupants.

There was no post-crash fire. The battery was torn away from the aircraft, which likely eliminated electrical ignition sources. Sparks generated by ground contact were likely suppressed by the steady rain and saturated terrain. These factors likely prevented the spilled fuel from igniting. The absence of a post-impact fire contributed to the survival of all of the aircraft’s occupants.

Incorrect fuel type

Supervision of the fuelling operation by the crew of the aircraft undergoing fuelling is an important administrative defence against risk, and is usually a stated requirement in the company operations manual and standard operating procedures (SOPs) of an air operator. It provides the opportunity for the crew to observe the signage and placarding on the fuelling equipment. The crew can also relay servicing information specific to the aircraft, as well as the fuel type and amount of fuel required, to the aircraft fuel handling technician (AFHT).

Other administrative defences include use of a standing fuel order list or a fuel order form, and the verbal confirmation that the AFHT should obtain about the fuel type and amount required. Comparison by the AFHT of the placarding adjacent to the aircraft's fuel filler openings with the fuel nozzle markings is also an administrative defence.

A physical defence exists in the form of the Jet-A1 flared spout, which will not normally fit into the AVGAS fuel filler opening. However, for various reasons, the use of the Jet-A1 flared spout is impossible, or impractical, on some turbine-powered aircraft. Aircraft that were manufactured prior to the current airworthiness standards, or that have been modified by the installation of turbine engines, may have fuel filler openings that do not meet the dimension requirements. The airworthiness standards for rotorcraft do not specify the size of fuel filler openings. As a result, fuelling equipment commonly includes a reduced-diameter spout that can be temporarily fitted for use with non-standard fuel filler openings. When a reduced-diameter spout is available to accommodate non-standard fuel filler openings, there is an increased risk that Jet-A1 fuel will be dispensed into an aircraft that requires AVGAS.

When a fuelling operation is finished, the AFHT should present the fuel slip to the crew for scrutiny and a signature. The crew has an opportunity to sample the fuel at the sump drains as part of the pre-flight check. However, depending on the concentrations of fuel present, it is uncertain how effective this sampling would be for detecting Jet-A1 fuel in AVGAS.

A number of administrative and physical defences have been introduced by aircraft operators, regulators, and fuel suppliers to address the risks associated with fuelling of aircraft. As a result, the aviation fuel supply chain is a robust and reliable system. However, if administrative and physical defences against errors in aviation fuel operations are circumvented or disabled, there is a risk that the incorrect type of fuel will be delivered.

Several factors likely allowed the fuelling error to go undetected in this occurrence. They included time pressure, the flight crew's trust in the fuel dealer that was based on previous experience, and the direction of their attention to other work-related tasks at the time of the fuelling. These factors likely resulted in the inattentional blindness that crew members experienced toward the fuel truck signage that might have alerted them to the error in fuel type.

The flight crew had developed certain levels of trust in various aerodrome fuel dealers that extended to those dealers' individual AFHTs. However, in this instance, the AFHT had approximately 1 month of experience fuelling aircraft and had only recently begun working unsupervised. The AFHT had completed the required training and received certification. Due to the AFHT's unfamiliarity with various aircraft types, the AFHT still required input from flight crews with respect to required fuel types and fuel filler locations.

Prior to the arrival of Keystone Air Service Ltd. flight KEE208, the AFHT was not familiar with the aircraft or the fuel type required, and drove the Jet-A1 truck to the aircraft. That the pilot-in-command (PIC) did not perceive the Jet-A1 placards on the fuel truck can likely be attributed to inattentional blindness. The PIC was busy with post-flight duties in the cockpit and had intended to relay the fuel load information. However, the task was assumed by the second-in-command (SIC) when it was noticed that the AFHT was having trouble identifying the fuel filler openings. After pointing out the fuel filler locations, the SIC relayed the fuel quantity information to the AFHT but did not specify the fuel type. The SIC did not notice the fuel truck signage either. The AFHT was required to present a fuel order form on which the crew would specify the fuel type and amount required. However, this form was almost never used by the fuel dealer's employees.

The fuelling operation was not adequately supervised by the flight crew. The AFHT commenced the fuelling operation, having received tacit approval to do so, after the SIC and PIC had gone to the airport terminal. The placards adjacent to the fuel filler openings were not compared with the markings on the Jet-A1 flared spout.

The Jet-A1 flared spout did not fit into the fuel filler opening, but the AFHT had encountered this mismatch on other aircraft types and had accommodated on those occasions by removing the Jet-A1 flared spout and installing the reduced-diameter spout. Consequently, a reduced-diameter spout was installed that enabled the delivery of Jet-A1 fuel into the AVGAS fuel filler openings. If a reduced-diameter spout is available to accommodate non-standard fuel filler openings, there is an increased risk that Jet-A1 fuel can be dispensed into an aircraft that requires AVGAS.

When the fuelling was completed, the AFHT printed a fuel slip, which recorded that Jet-A1 fuel had been dispensed. When the AFHT left the building, the fuel slip remained inside. The PIC could not gain access through the locked ground-side door of the building, and the crew did not try the air-side door while returning to the aircraft. As a result, the fuel slip indicating that Jet-A1 fuel had been delivered was not available for scrutiny by the crew.

Because the aircraft had been depowered and left unattended during the stopover, the SOPs required the pre-flight checks carried out by the crew to include fuel sampling. However, the normal practice was to take samples prior to the first flight of the day only. Samples from the 4 fuel-cell sumps might have indicated the presence of Jet-A1 fuel. Prior to the engines being started, it is likely that a sample from the 2 fuel filter bowls would have yielded mostly AVGAS.

When the crew started the engines, the AVGAS remaining in the fuel lines and fuel filter bowls was being consumed. The expedited taxi to the runway meant that the aircraft was airborne before the fuel mixture, consisting of approximately 32% AVGAS and 68% Jet-A1, reached the engines. Given that the fuel mixture was present in all 4 fuel tanks, attempts to restore engine power by selecting another fuel tank would have been unsuccessful. The crew therefore had to contend with the decreasing power output, and inevitable failure, of both engines. An off-airport forced landing was the only option remaining. Delivery of the incorrect type of aircraft fuel caused loss of power from both engines, necessitating a forced landing.

Findings

Findings as to causes and contributing factors

1. Delivery of the incorrect type of aircraft fuel caused loss of power from both engines, necessitating a forced landing.

2. The fuelling operation was not adequately supervised by the flight crew.

3. A reduced-diameter spout was installed that enabled the delivery of Jet-A1 fuel into the AVGAS fuel filler openings.

4. The fuel slip indicating that Jet-A1 fuel had been delivered was not available for scrutiny by the crew.

Findings as to risk

1. If administrative and physical defences against errors in aviation fuel operations are circumvented or disabled, there is a risk that the incorrect type of fuel will be delivered.

2. If a reduced-diameter spout is available to accommodate non-standard fuel filler openings, there is an increased risk that Jet-A1 fuel can be dispensed into an aircraft that requires AVGAS.

Other findings

1. Aircraft that were manufactured prior to the current airworthiness standards, or that have been modified by the installation of turbine engines, may have fuel filler openings that do not meet the dimension requirements.

2. The airworthiness standards for rotorcraft do not specify the size of fuel filler openings.

3. The use of all of the available restraint systems in the aircraft contributed to the survival of the occupants.

4. There was no post-crash fire, likely due to the separation of the battery from the aircraft and to the rain-saturated crash site.

5. The absence of a post-impact fire contributed to the survival of all of the aircraft's occupants.

Safety action

Safety action taken

Keystone Air Service Ltd.

On 16 September 2015, an urgent memo was generated by Keystone Air Service Ltd.'s (Keystone) operations manager and circulated to all Keystone pilots. The memo reiterated the importance of crew supervision of aircraft fuelling and expectation of compliance with Keystone *Company Operations Manual* section 4.12.6 Supervision of Fuelling.

Transport Canada

In accordance with Transport Canada (TC) policy and procedures, a post-accident program validation inspection was conducted on 21–25 September 2015. The inspection revealed safety concerns that resulted in the suspension of Keystone's air operator certificate. Subsequently, TC conducted an in-depth review of Keystone's aviation safety record. On 29 December 2015, the Minister of Transport cancelled Keystone's air operator certificate, citing public interest and the company's aviation safety record.

This report concludes the Transportation Safety Board's investigation into this occurrence. The Board authorized the release of this report on 10 August 2016. It was officially released on 06 September 2016.

Visit the Transportation Safety Board's website (www.tsb.gc.ca) for information about the TSB and its products and services. You will also find the Watchlist, which identifies the transportation safety issues that pose the greatest risk to Canadians. In each case, the TSB has found that actions taken to date are inadequate, and that industry and regulators need to take additional concrete measures to eliminate the risks.

Appendix A – Imperial Overwing Fuelling poster

Appendix B – Misfuelling events in the TSB database

TSB File #	Inv Class		Flown	Fixed-wing	Rotary-wing
A80Q0056	Nil	Britten-Norman Islander	YES	X	
A83O4077	Nil	Piper PA-31	YES	X	
A88Q0058	C5	Piper PA-28	YES	X	
A92W0078	C5	Rockwell Aero Commander 685	No	X	
A93O0287	C5	Canadair CL215	No	X	
A97A0131	5	Piper PA-31	YES	X	
A97A0132	5	Hughes 269C	YES		X
A97C0140	5	Beech 60 Duke	YES	X	
A98C0114	5	Piper PA-31-350	YES	X	
A98O0292	5	Schweizer 269C (300C)	YES		X
A99F0064	5	Piper PA-31	YES	X	
A00O0181	5	Cessna 414	YES	X	
A02P0089	5	Piper PA23-250	YES	X	
A05P0063	5	De Havilland DHC-2	YES	X	
A07Q0230	5	Piper PA-31	YES	X	
A07W0228	5	Piper PA-31-350	YES	X	
A10C0123	3	Rockwell Aero Commander 500S	YES	X	
A11Q0036	3	3 Robinson R44 IIs	YES		X
A15F0029	5	Piper PA-46-350P	YES	X	
A15C0134	3	Piper PA-31-350	YES	X	
A16Q0059	5	Piper PA-31	YES	X	