Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

AVIATION INVESTIGATION REPORT
A13P0127

MID-AIR COLLISION

CESSNA 150F, C-FSQQ
AND
STEMME S10-VT, C-FHAB
PEMBERTON, BRITISH COLUMBIA, 3 NM W
29 JUNE 2013

Canada

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

Aviation Investigation Report A13P0127

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Summary

The privately registered Cessna 150F (registration C-FSQQ, serial number 15061702) departed Lillooet, British Columbia, for Nanaimo, British Columbia, with the pilot, 1 passenger, and a dog on board. A privately registered Stemme S10-VT motor glider (registration C-FHAB, serial number 11-016) was inbound to Pemberton, British Columbia, after a local sightseeing flight, with the pilot and 1 passenger on board. Both aircraft were being operated in accordance with visual flight rules. At approximately 1218 Pacific Daylight Time, the 2 aircraft collided about 3 nautical miles west of Pemberton and struck the ground in the Nairn Falls Provincial Park Campsite. There were 2 main accident sites about 0.3 nautical miles apart. Both aircraft were destroyed, and there were no survivors. There was an intense post-impact fire, which consumed the cockpit and engine compartment of the glider. The Cessna engine compartment suffered a small post-impact fire, which self-extinguished. No emergency locator transmitter signals were detected at the time of the accident.

Ce rapport est également disponible en français.

Factual information

History of the flights

After refueling at 1117,[1] the privately registered Cessna 150F (registration C-FSQQ, serial number 15061702) departed Lillooet, British Columbia, for Nanaimo, British Columbia. A visual flight rules (VFR) flight plan was filed, and the route was to follow the preferred VFR route along Highway 99 through the mountains to Nanaimo. No cruising altitude was stated in the flight plan. There was no communication with air traffic services (ATS). Such communication is not required in the Class G uncontrolled airspace in which the flights were being operated. The Cessna was observed from the ground on a heading of approximately 200° magnetic (M) just prior to the collision.

The privately registered Stemme S10-VT motor glider (registration C-FHAB, serial number 11-016) was on a local VFR sightseeing flight. There was no contact with ATS. The propeller of the glider was found in the stowed position, indicating that the aircraft was operating as a glider at the time of the accident. The glider was observed on a heading of approximately 040 °M just prior to the collision.

Neither aircraft was visible on ATS radar, as they were estimated to be at 4000 feet above sea level (asl), which is below the mountain peaks in the area.

Handheld global positioning system (GPS) units were recovered from both aircraft. Neither had been powered up on the day of the accident, and no track or altitude data were available from them.

Pilots

The pilot of the Cessna held a private pilot licence (aeroplane), valid for single-engine land aircraft, with a valid Category 3 medical certificate, which required that the pilot wear glasses when flying. The pilot had accumulated 127 total flight hours on the Cessna 150 and 172 aircraft types. The licence was issued 9 months prior to the accident. Records indicate that this pilot was certified and qualified for the flight in accordance with existing regulations.

The pilot of the glider held a private pilot licence (aeroplane), valid for single-engine land aircraft, and a glider pilot licence with a valid Category 3 medical certificate, which required that the pilot have glasses available when flying. The pilot had accumulated over 2500 total flight hours on gliders and over 780 total flight hours on single-engine aircraft. Records indicate that the pilot was certified and qualified for the flight in accordance with existing regulations.

It could not be determined whether either pilot was wearing glasses at the time of the accident. The Cessna pilot normally wore a baseball-type cap when flying.

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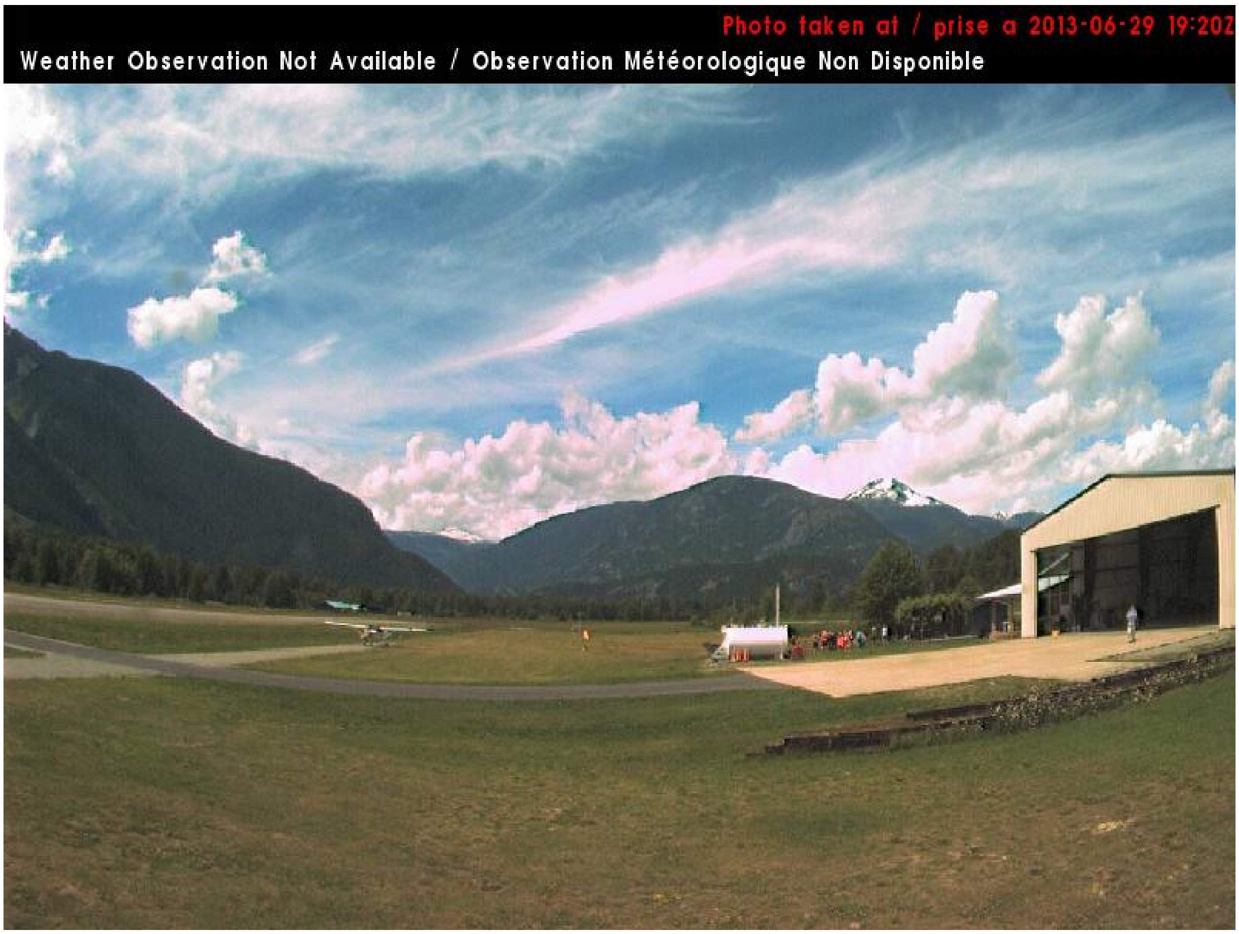
1 All times are Pacific Daylight Time (Coordinated Universal Time minus 7 hours).

Weather

The weather at the Pemberton Airport was clear and the winds were calm at the time of the occurrence. The air temperature was 24 °C. A west-facing weather camera at the airport captures images every 10 minutes. White cumulus clouds could be seen south of the Nairn Falls Provincial Park campsite (Photo 1).

Photo 1. View at Pemberton Airport facing west, taken around the time of the accident



Aircraft

The Cessna (Photo 2), manufactured in 1965, had accumulated 6319 hours since new. The aircraft was powered by a Continental O-200-A engine. Records indicate that the aircraft was certified, equipped and maintained in accordance with existing regulations and approved procedures. Strobe lights had been added to the Cessna. A circuit breaker labeled STROBE LIGHTS PUSH ON was found on the instrument panel. The circuit breaker was destroyed in the accident, and it could not be determined whether the strobe lights were functioning during the flight. It could also not be determined whether the landing light of the Cessna was on at the time of the occurrence.

The radio installed was a Bendix/King KY97A, which is not capable of monitoring more than one frequency at a time. The transponder installed was a King KT76A, and its power switch was found in the ON position, but it could not be determined what code was selected or whether the unit was functioning during the flight.

Photo 2. Cessna 150F, C-FSQQ

A 406-megahertz (MHz) emergency locator transmitter (ELT) with a sheared-off antenna cable was found with the Cessna wreckage.

The glider (Photo 3), manufactured in 1998, had accumulated just over 600 hours since new. It was powered by a Rotax 914 F2 engine for self-launch capability. After take-off, landing gear is retracted. At altitude, the engine is shut down and the propeller retracts into the moveable nose cone. The pilot and passenger sit side by side in a semi-reclined position behind the glare shield of the instrument panel.

Photo 3. Stemme S10-VT, C-FHAB

Records indicate that the aircraft was certified, equipped and maintained in accordance with existing regulations and approved procedures.

The glider was not equipped with strobe, navigation or landing lights, nor were they required by regulation. The glider had a Terra TX 760 D radio, which is not capable of monitoring more than one frequency at a time. The transponder installed was a Terra TRT 250 D. It could not be determined whether the transponder was operating during the flight. There was a recent notation in the journey logbook of the glider: “ELT EXEMPT CARs 605.38(3)a.” A fire-damaged unit, which appeared to be an ELT, was found. However, its switch positions and serviceability could not be determined.

The Canadian Type Certificate Data Sheet A-181 for the Stemme S10-VT states, "All external portions of the powered sailplane exposed to solar radiation must be painted white…" [2] Also, by design, the wings of the glider are very thin when viewed from in front or behind.

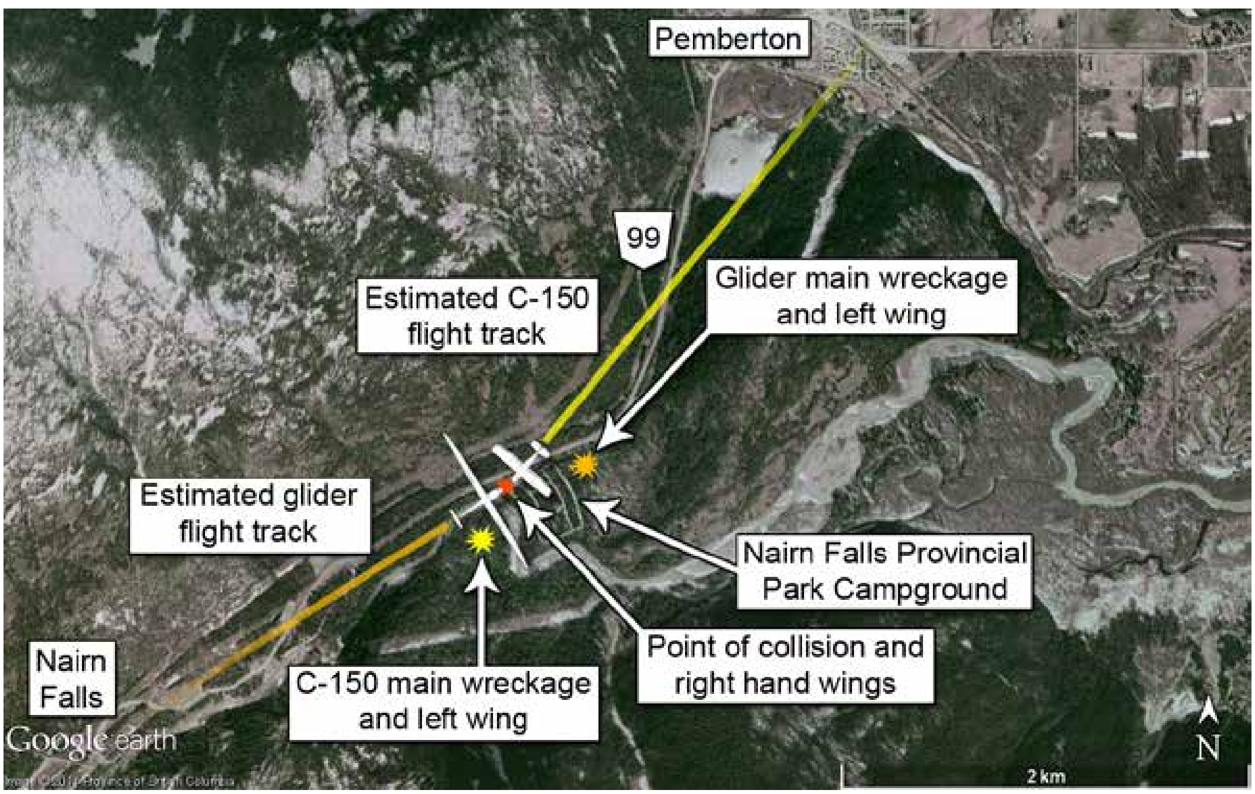
Neither aircraft was equipped with a flight data recorder (FDR) or a cockpit voice recorder (CVR), nor was either required by regulation. Both aircraft were equipped with lap and shoulder restraints.

TSB calculated a weight and balance for both aircraft with the data available, and these were not determined to be a factor in this accident.

Collision and wreckage information

The collision occurred at a narrowing of the valley. The right-hand wing of the Cessna dropped sharply just prior to the collision. Both of the aircrafts' right wings made contact. At the time of the collision, the glider's wings were level, and the Cessna was right-wing low. Both of the right wings were detached from the fuselages during the collision (Figure 1).

Figure 1. Estimated flight path and collision point with location of main wreckage.



2 Transport Canada, Type Certificate Data Sheet no. A-181, Issue no. 2 (approved 15 September 1998, issued 30 November 1998), V. Supplements and Restrictions, 2.

The right wing of the glider was found in 2 sections. The Cessna's right wing and the outboard section of the glider's right wing landed 150 feet apart. The inboard section of the glider's right wing was found 170 feet beyond the outboard section.

The campground, which is at 800 feet asl, was littered with debris from both aircraft. The glider spiraled down and was found 1100 feet from both right wings. Due to the fire damage, it could not be determined whether the pilot and passenger restraints were intact.

The Cessna descended rapidly on a heading of approximately 210 °M, with the sound of the engine revolutions per minute (rpm) increasing. The instrument panel, engine compartment, and nosewheel were found together in one area. The lower fuselage, seats, and main landing gear were found together in another area close by. Both of these groups of wreckage were inverted and on the forest floor. The heavily damaged aft fuselage and tail section was found in a stand of trees 20 feet away, along with the left-hand wing, which was detached. The pilot's seat restraint was severed during the collision, and the pilot was ejected from the aircraft prior to impact. The passenger's seat restraint was intact.

There were no physical injuries to people on the ground.

Communications

The *Transport Canada Aeronautical Information Manual* (TC AIM), under the section Rules of the Air and Air Traffic Services, states in part:

> An Aerodrome Traffic Frequency (ATF) is normally designated for active uncontrolled aerodromes that do not meet the criteria listed in RAC 4.5.4 for an mandatory frequency (MF). The ATF is established to ensure that all radio-equipped aircraft operating on the ground or within the area are listening on a common frequency and following common reporting procedures. The ATF will normally be the frequency of the UNICOM (universal communications) where one exists or 123.2 MHz where a UNICOM does not exist.[3]

This section also states, in part:

> (a) Radio-equipped Aircraft: The following reporting procedures shall be followed by the pilot-in-command of radio-equipped aircraft at uncontrolled aerodromes within an MF area and should also be followed by the pilot-in-command at aerodromes with an ATF:
>
> (i) *Listening Watch and Local Flying* [CAR 602.97 (2)]
> Maintain a listening watch on the mandatory frequency specified for use in the MF area. This should apply to ATF areas as well.
>
> […]
>
> (vi) *Flying Through an MF Area* (CAR 602.103)

[3] Transport Canada, TP 14371, *Transport Canada Aeronautical Information Manual* (TC AIM) (04 April 2014), RAC – Rules of the Air and Air Traffic Services, section 4.5.5. Aerodrome Traffic Frequency.

> (A) Report before entering the MF or ATF area and, where circumstances permit, shall do so at least five minutes before entering the area, giving the aircraft's position and altitude and the pilot-in-command's intentions; and,
>
> (B) Report when clear of the MF or ATF area.
>
> NOTE: In the interest of minimizing possible conflict with local traffic and minimizing radio congestion on the MF or ATF, pilots of en-route VFR aircraft should avoid passing through MF or ATF areas.[4]

Collision avoidance under visual flight rules

Pilots operating under VFR must maintain a continuous lookout for other aircraft, and are responsible for collision avoidance. Collision avoidance in visual meteorological conditions is based on the see-and-avoid principle, which is described, in part, as follows:

> This concept requires that vigilance shall be maintained at all times, by each person operating an aircraft, regardless of whether the operation is conducted under Instrument Flight Rules (IFR) or Visual Flight Rules (VFR).[5]

As well, the *Canadian Aviation Regulations* (CARs) list the requirements for VFR right of way.[6] In addition to the basic see-and-avoid principle, the CARs also require that VFR aircraft transmit traffic advisories when operating in and around aerodromes in uncontrolled airspace. Such traffic advisories alert pilots to the presence of other aircraft and aid in VFR collision avoidance. There are provisions in the CARs for aircraft with no radio equipment (NORDO) to use uncontrolled airspace and aerodromes with an assigned air traffic frequency, such as Pemberton. The *Canada Flight Supplement* lists the aerodrome traffic frequency (ATF) for Pemberton as 123.2 MHz and applies to a radius of 2 nautical miles (nm) and a height of 3000 feet asl.

The pilot of the glider broadcasted on 123.2 MHz over Nairn Falls while inbound to Pemberton for landing. This broadcast was heard by another pilot flying in the area who could not recall the altitude reported in the broadcast. Information gathered during the investigation determined that the pilot of the glider always monitored 123.2 MHz while operating in the valley area, regardless of altitude or distance from the Pemberton airport. Other local operators had aircraft equipped to monitor 2 frequencies and would listen on 123.2 MHz and 126.7 MHz, which is the standard enroute frequency for the area. It was determined that, even though the Cessna was outside of the ATF, it too was tuned to 123.2 MHz and should have been able to hear the glider's broadcast.

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4 Ibid., section 4.5.7. VFR Communication Procedures at Uncontrolled Aerodromes with MF and ATF Areas

5 United States Federal Aviation Administration (FAA), Advisory Circular 90-48C, Pilots' Role in Collision Avoidance (18 March 1983), 4.a.(1).

6 Transport Canada, SOR/96-433, *Canadian Aviation Regulations* (CARs), Subsection 602.19(2).

Limitations of the see-and-avoid principle

Several published studies address the shortcomings of the see-and-avoid principle[7] relied upon as a sole means of collision avoidance. Previous reports summarize by stating that "failures to see and avoid are due almost entirely to the failure to see."[8]

Research has shown that it takes approximately 12.5 seconds (Appendix A) for a pilot to take evasive action upon recognition of an impending collision.[9] In addition to reaction time, distance is another critical factor that affects a pilot's ability to see and avoid a collision (Figure 2). This is especially true for aircraft beyond 2 nm, which are extremely difficult to see. Several physiological factors tend to exacerbate this difficulty, namely the following:

- Relative aircraft position;
- Empty field myopia, a condition under which the crystalline lens in the human eye tends to focus on a point 3 to 5 feet in front of the eye;
- Limited field of vision, a frequent occurrence in which aircraft window supports and cabin structure block fields of vision, resulting in a limited field of vision; and
- Blind spots,[10] which are a characteristic of the human eye. The blind spot is located where the optic nerve connects to the eye. If something obstructs one eye's view (such as aircraft structure) the viewed object may be in the remaining eye's blind spot, causing it to disappear.

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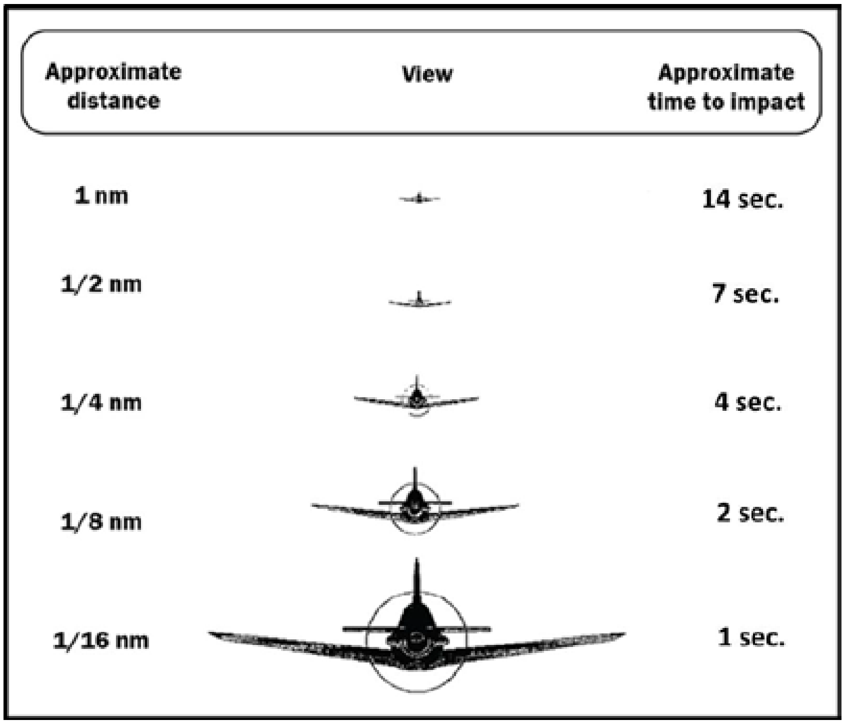
7 Australian Transport Safety Bureau (ATSB), Research Report: *Limitations of the see-and-avoid principle* (April 1991).

8 W. Graham, Federal Aviation Administration (FAA) Report No. DOT/FAA/CT-TN/89/18, *See and Avoid/Cockpit Visibility* (October 1989), as quoted in TSB Aviation Investigation Report A06O0206.

9 U.S. Department of Transportation, Federal Aviation Administration (FAA), Advisory Circular AC 90-48C, Pilots' Role in Collision Avoidance (18 March 1983), Appendix 1.

10 Transport Canada, TP 12863, *Human Factors for Aviation – Basic Handbook* (2003).

Figure 2. Time to impact for 2 aircraft approaching each other at 250 knots (Source: Transport Canada, TP 12863, *Human Factors for Aviation – Basic Handbook* [2003])



Aircraft on converging tracks, such as the 2 aircraft involved in this occurrence, can be difficult to see, because there is very little relative motion apparent to the observer. The relative bearing between 2 converging aircraft remains constant as they converge. This results in the aircraft appearing stationary to each other, making each aircraft less conspicuous to the other.

It is also normal for a VFR pilot to look at the horizon and below to maintain level flight and keep track of the flight's progress. Aircraft on a collision course from above may not be in the lower aircraft pilot's field of vision until it is too late to avoid a collision.

The closing speed of the aircraft in this accident would have been between 150 and 200 knots due to the variable cruising speed of the glider.

Collision avoidance manoeuvres

While it is normal for persons to turn to avoid collisions, when 2 aircraft are on a collision course, the optimum avoidance response will differ depending on the time to impact. Once the aircraft are inside the range of approximately 10 seconds to impact, the pilot should employ an altitude change only. This conclusion takes into consideration that, when 2 aircraft are confined in close quarters, the essential action is to minimize the relative cross-sectional areas of each aircraft. Under these circumstances, it has been generally found that any application of bank will increase the relative cross-sectional area and thereby increase the probability of impact. As an example, an aircraft with a vertical cross-section of approximately 13 feet, when in level flight, will have a vertical cross-section in the range of 28 to 34 feet, at bank angles in the range of 45° to 60°. The final value of the vertical cross-section will be dependent on the aircraft's wing span and on the applied bank angle.

Collision avoidance systems

There are essentially 2 types of collision avoidance systems available for installation in aircraft: active systems, known as traffic collision avoidance systems (TCAS), and passive systems, marketed under a variety of descriptions depending on their function.

A passive system, such as the portable collision avoidance system (PCAS), relies on the premise that aircraft at different altitudes cannot collide. The following is a comparison of active versus passive collision avoidance systems:

TCAS, the active systems:

- require a special mode S transponder;
- have a greater range of traffic detection (up to 40 nm);
- transmit extensive and complex data, which can be received and decoded by another TCAS system; and
- provide detailed avoidance instructions to pilots.

Passive systems:

- rely on other aircrafts' transponder interrogation-reply signals,
- have a limited detection range of up to 7 nm, and
- provide limited avoidance instructions.

Whereas active TCAS systems transmit interrogation messages similar to those sent by the surveillance radar systems of air traffic services, which cause the transponders of receiving aircraft to reply, passive systems rely on replies generated as the result of other interrogators (either radar or TCAS). If a target aircraft is out of radar coverage, its transponder will not send replies, and it will be invisible to a passive collision avoidance system.

There is currently no requirement for Canadian-registered private aircraft to be equipped with active or passive collision avoidance systems. Consequently, there is no regulatory guidance as to their use. It is important to note that these passive systems are intended only as a supplement to the visual acquisition of traffic.

Neither aircraft in this accident was fitted with this type of equipment, nor was it required by regulation.

A list of some of the systems available, along with their advantages, disadvantages and approximate cost, is shown in Appendix B (originally published in TSB Aviation Investigation Report A12H0001).

TSB Laboratory reports

The following TSB Laboratory reports were completed and are available from the TSB upon request:

- LP 131/2013 – 2 GPS Units
- LP 143/2013 – Data Extraction

Analysis

There is no indication that either an aircraft malfunction or the weather in the immediate area contributed to this occurrence.

In this occurrence, the potential for each pilot to see the other aircraft would have been reduced by a number of factors. The 2 aircraft were on intersecting tracks that were 10° off of nose-to-nose. The glider was likely descending, so it would have been coming from above. A glider's pilot and passenger sit in a semi-reclined position behind the instrument panel and nose cone. Visibility forward and below the nose is limited. The Cessna pilot's normal scan during the cross-country flight would have been primarily downwards, and the Cessna pilot was probably wearing a baseball-type cap with a sun visor in front. Visibility above would have been limited. Additionally, the pure white glider, with its very thin profile wings, would have been difficult to see with white cumulus clouds in the background. As well, physiological issues related to vision may have further reduced the pilots' available reaction time and resulted in their inability to avoid one another.

The relative position of each of the occurrence aircraft just before the collision would have made visual acquisition difficult. The collision dynamics and observations from the ground indicated that the Cessna pilot may have seen the glider just before collision. Because the glider appeared to remain in stable flight until the collision, it is likely that the glider pilot did not see the Cessna or did not see it in time to attempt an avoidance manoeuvre. The converging 3-dimensional tracks of the 2 aircraft caused blind spots for the pilots. That factor, coupled with physiological vision limitations, reduced opportunities for collision detection. As a result, the available reaction time was reduced to a point at which a mid-air collision could not be avoided.

The right wings and other pieces from both aircraft were shorn off in mid-air during the collision, rendering both aircraft uncontrollable, and the subsequent collision with terrain was not survivable.

The failure of the see-and-avoid principle to avert this collision illustrates the residual risk associated with reliance on that principle as the sole means of collision avoidance. If the see-and-avoid principle is relied upon as the sole means of collision avoidance when operating in visual flight rules conditions, then there is a continued risk of collision.

Findings

Findings as to causes and contributing factors

1. The converging 3-dimensional tracks of the 2 aircraft caused blind spots for the pilots. That factor, coupled with physiological vision limitations, reduced opportunities for collision detection. As a result, the available reaction time was reduced to a point at which a mid-air collision could not be avoided.

2. The right wings and other pieces from both aircraft were shorn off in mid-air during the collision, rendering both aircraft uncontrollable, and the subsequent collision with terrain was not survivable.

Findings as to risk

1. If the see-and-avoid principle is relied upon as the sole means of collision avoidance when operating in visual flight rules conditions, then there is a continued risk of collision.

This report concludes the Transportation Safety Board's investigation into this occurrence. The Board authorized the release of this report on 31 July 2014. It was officially released on 18 September 2014.

Visit the Transportation Safety Board's website (www.bst-tsb.gc.ca) for information about the Transportation Safety Board 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.

Appendices

Appendix A — Recognition and reaction times

Table 1. Time to closest approach point (CAP), based on closing speeds

Running time	Action	Seconds
00:00	See object	0.1
00:00	Recognize aircraft	1.0
00:01	Become aware of collision course	5.0
00:06	Decision to turn left or right	4.0
00:10	Muscular reaction	0.4
00:10	Aircraft lag time	2.0
00:12	TOTAL TIME	12.5

Table 2. Time to impact (in seconds, extrapolated from FAA data), based on distance apart and closing speeds

Range	600 mph	360 mph	194 knots
10 miles	60 s	100 s	160 s
6 miles	36 s	60 s	97 s
5 miles	30 s	50 s	80 s
4 miles	24 s	40 s	64 s
3 miles	18 s	30 s	48 s
2 miles	12 s	20 s	32 s
1 mile	6 s	10 s	16 s
0.5 mile	3 s	5 s	8 s
0.25 miles	1.5 s	2.5 s	4 s

Appendix B – Airborne collision avoidance systems

Traffic alert and collision avoidance system (TCAS) I:

- is intended for general aviation and regional airlines.
- issues traffic advisories (TAs) that assist pilots to visually acquire target aircraft.
- is an active system consisting of a transmitter, receiver, directional antennas, computer, and cockpit displays.
- transmits a signal (interrogation) that will be received by an aircraft equipped with a Mode C transponder . That aircraft will respond to the interrogation and reply. The system will then interpret the reply and calculate the distance and direction of the responding aircraft.
- is able to determine the responding aircraft's relative altitude and whether it is climbing or descending.
- issues a traffic advisory (visually and aurally) if a potential conflict is determined.
- has been mandated by the FAA for installation on aircraft with 10 to 30 seats.

Advantages

- provides a basic level of surveillance to flight crews.

Disadvantages

- requires that conflicting aircraft be equipped with a transponder.
- transmits only on 1030 / 1090-MHz frequencies; as the density of TCAS-equipped aircraft increases, there is a corresponding increase in interrogations of transponders.
- provides advisory alerts only; the crew is still required to assess the situation and determine a resolution.

Cost in 2012: Approximately $22 000 USD (other units range from $28 000 to $74 000)

Traffic alert and collision avoidance system (TCAS) II:

- uses Mode S[1] transponders.
- issues traffic advisories (TAs) that assist pilots in visually acquiring target aircraft.
- analyzes the projected flight path of approaching aircraft and will issue resolution advisories (RAs) to the crew in order to resolve potential conflicts. The RA will advise the pilot to climb or descend in order to resolve the conflict. Some models may also advise the pilot not to manoeuvre.
- are required internationally in aircraft with more than 30 seats or weighing more than 15 000 kg.

Advantages

- When resolving conflicts with TCAS II-equipped aircraft, the TCAS II units will co-ordinate RA in order to avoid mirroring their manoeuvres.

Disadvantages

- Conflicting aircraft are required to be equipped with transponders.
- restricted to provide commands for vertical manoeuvring, and not for turns.
- If not communicated to ATC in a timely manner, RA manoeuvring may cause the controller to issue avoidance instructions that may conflict with RA.

Cost in 2012: $150 000 to $230 000 USD

Traffic advisory system:

- interrogates other Mode A, C, and S transponder systems and listens for a target reply, then calculates as much distance, relative bearing, altitude, and vertical trend as possible.
- issues a traffic alert (TA) if the system calculates a collision course.

Advantages

- works on the ground and will work with any aircraft with an installed and functioning transponder.
- is a lower-cost evolution of TCAS.

Disadvantages

- Installations are significant, and include heavy and large remote processors and complex antenna work.

Cost in 2012: $10 000 to $20 000 USD

Portable collision alert system (PCAS):

- is a passive system that listens for a 1090-MHz transponder transmission.
- can be temporarily mounted on the dash or permanently panel-mounted.
- certain units can provide directional and altitude information from transponder-equipped aircraft. (Altitude information can be provided only from aircraft equipped with transponders that have altitude-encoding capability.)
- has a maximum range of approximately 6 nm.
- The parent unit will interpret the target's coded data and provide a relative position and altitude.

Advantages

- are relatively inexpensive, with a minimal investment in installation.
- can be readily utilized.
- when coupled with GPS mapping equipment, the relative position of target aircraft can be better appreciated.

Disadvantages

- requires that target aircraft be transponder-equipped, and that the target aircraft be interrogated by an air traffic control ground station (or from airborne TCAS-equipped aircraft), resulting in the transponder replying to that interrogation.
- Depending on where the unit is located, there is a potential for shadowing by the parent aircraft's structure.
- Units have also been reported to alert bogus targets. It has been suggested that this phenomenon may be due to the unit reading the parent aircraft's transponder signal.

Cost in 2012: $550 to $1500 USD

Traffic information system (TIS):

- is a ground-based service that utilizes the Mode S datalink to communicate collision avoidance information to the aircraft.
- The system can show location, direction, altitude, and climb / descent trends of other transponder-equipped aircraft within 5 nm and 1200 feet of its owner's aircraft.
- Threat traffic information can be displayed on the Mode S transponder or a variety of cockpit units, including many popular multi-function displays.

Advantages

- has no distinct advantage.

Disadvantages

- requires aircraft to be equipped with a Mode S transponder.
- may not be available in all areas.
- is ground-based; aircraft can fly out of range.
- needs a multi-function cockpit display.

Cost in 2012: $5000 USD (not installed)

Automatic dependent surveillance – Broadcast (ADS-B):

- is the system being implemented by the FAA, with ADS-B (Out) implemented by 2020.
- Each aircraft is responsible for its own navigation and separation.
- ADS-B aircraft transmit their identification, speed, and vertical and horizontal positions to a global navigation satellite system (GNSS). This information would be rebroadcast by the GNSS to other ADS-B-equipped aircraft and ground stations (ATC). Information will be broadcast on 1090 MHz or 978 MHz.

Advantages

- The system is not radar dependent; therefore, distance from a radar site and terrain will not interfere with the transmission / reception of data. The system will provide pilots and air traffic controllers with real-time, precise aircraft position information.

Disadvantages

- Not many aircraft are equipped with this system, so there will be a reliance on traditional radar until such time as the program has been implemented.

Cost in 2012: $8000 USD (not installed)

FLARM:

- obtains its position from an internal GPS and a barometric sensor, and then broadcasts this with forecast data about the future 3D flight track. Its receiver listens for other FLARM devices within typically 3–5 km and processes the information received. Motion-prediction algorithms predict potential conflicts for up to 50 other signals and warn the pilot using sound and visual means.
- can store information about static aerial obstacles, such as cables, in a database.
- The system's serial data protocol is public, while the prediction engine of the FLARM radio-protocol is proprietary and licensed to manufacturers. The prediction engine itself is patented by Onera (France).

Advantages

- is small in size.
- requires simple installation.
- requires low power consumption.
- provides visual and acoustic warnings for aircraft and fixed obstacles.

Disadvantages

- optimized for the specific needs of small aircraft, such as gliders, and not for long-range communication or ATC interaction.
- requires other aircraft to be equipped with FLARM.

Cost in 2012: $900 USD (not installed)