

Transportation Safety Board
of Canada



Bureau de la sécurité des transports
du Canada

AVIATION INVESTIGATION REPORT
A06O0206



MID-AIR COLLISION

**BETWEEN CESSNA 172P C-GFGD
AND CESSNA 182T C-GCHN
CALEDON, ONTARIO, 1 nm W
04 AUGUST 2006**

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

Mid-Air Collision

Between Cessna 172P C-GFGD
and Cessna 182T C-GCHN
Caledon, Ontario, 1 nm W
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Summary

On 04 August 2006, two light aeroplanes collided in mid-air approximately 1 nm west of the town of Caledon, Ontario. Both aeroplanes were operating in accordance with visual flight rules in Class E airspace. The collision involved a Cessna 172P aeroplane (serial number 17275680, registration C-GFGD) operated by the Brampton Flying Club and being flown by an instructor and student, and a Cessna 182T aeroplane (serial number 18281612, registration C-GCHN) being flown by its owner. C-GFGD was southeastbound in a gradual descent, wings level. C-GCHN was northbound in straight and level flight. The angle between the tracks of the two aeroplanes was approximately 120°.

During the collision, the right wing was torn from C-GCHN and the aeroplane became uncontrollable. C-GFGD sustained damage to the nose and cockpit areas. Both aeroplanes crashed in close proximity to the point of collision. The three occupants of the aeroplanes received fatal injuries and both aeroplanes were destroyed. There was a small post-impact fire as a result of debris from one aeroplane severing an electrical power line. There was no fire in the main wreckage of either aeroplane. The accident took place at 1234 eastern daylight time at 43°51'29.6" N, 080°1'12.8" W.

Ce rapport est également disponible en français.

Other Factual Information

The collision occurred in daylight conditions that were suitable for visual flight, and the sun was high. Neither the weather nor the sun was a factor in the accident.

The Cessna 172, registration C-GFGD, was signed out for an instructional flight in preparation for the student pilot's private pilot flight test. The instructor pilot was pilot-in-command and carried overall responsibility for the conduct of the flight. The student pilot was most likely the pilot flying the aeroplane and would be expected to carry out all of the appropriate checks and functions. One of the instructor's roles is to monitor the performance and techniques used by the student in carrying out this and other cockpit functions. The Cessna 182, registration C-GCHN, was on a visual flight rules (VFR) flight plan from Burlington Airpark, Ontario, to Collingwood Airport, Ontario, to the Parry Sound Area Municipal Airport, Ontario. The flight planned altitude was 3500 feet.

All the crew members of the aeroplane were appropriately qualified, held valid medical certificates, had normal corrected or uncorrected vision, and were familiar with local conditions. The results of the autopsies and review of medical history did not indicate incapacitation or impairment before the collision. Both aeroplanes were equipped with three-point lap/shoulder restraints. C-GCHN was also equipped with lap-belt air bags. Impact forces were outside the design limits of the restraint systems and the impact was not survivable.

Radar data indicated that C-GFGD was descending progressively from 3800 feet to 2400 feet on a southeasterly track toward the Brampton Airport while C-GCHN was northbound toward Collingwood maintaining an altitude of 2400 feet. The two aeroplanes converged at an angle of 120° with a rate of closure of approximately 200 knots (340 feet per second). The flight paths and collision geometry are depicted in Appendices A and B. Each aeroplane presented an aspect angle 30° to the other.

Examination of the wreckage indicated that the aeroplanes struck each other as shown in Appendix C, wings level and heading unchanged, indicating that neither aeroplane took evasive action. The right wing detached from the fuselage of C-GCHN. The main wreckage of each aeroplane was found along its direction of flight. There was no indication of pre-impact damage or discrepancy affecting the operation of either aeroplane before the collision. Records for each aeroplane indicate that both were maintained in accordance with applicable regulations. There was property damage to the electrical power line and to a soy field in which one aeroplane crashed.

Both aeroplanes were equipped with anti-collision strobe lights and normal practice was for them to be on during flight. Both aeroplanes were equipped with functioning transponders. C-GCHN was also equipped with a traffic information service (TIS) system that can provide a display of nearby aircraft using information provided by ground-based radar; this service is not available in Canada. Neither aeroplane was equipped with a traffic alert and collision-avoidance system (TCAS) nor was such equipment required by regulation. Both aeroplanes had single-piece front windshields, which were in good condition. Field of view and position of the other aeroplane and of the sun are presented in Appendix D.

The collision occurred in Class E airspace (see Appendix A) where there is no requirement for an air traffic control (ATC) clearance or radio contact with air traffic services. In this type of airspace, there is no requirement for position reports, traffic advisory calls, or for aircraft to be on a common very high frequency (VHF) radio frequency. Aircraft are not required to have a communication radio, a radar transponder, or collision-avoidance equipment on board. It is unlikely that there was any communication between the two aircraft.

The Brampton Flying Club uses a practice area west of Orangeville, Ontario (see Appendix A), for flight training. The flying club has a standard procedure to fly a track parallel to Highway 10 between the Brampton Airport and the practice area, staying to the northeast of the highway outbound to the area and over gravel pits about one mile southwest of the highway returning to the airport. Neither the practice area nor the routes to and from Brampton Airport are published; both are heavily used. Terrain elevation in the area is 1400 to 1500 feet above sea level (asl). There are built-up areas and noise-sensitive locations in the vicinity, and aircraft normally maintain 1000 feet above ground level (agl) in the area. The floor of nearby Class C airspace is 2500 feet asl; therefore, aircraft without an ATC clearance must maintain 2400 feet asl or lower. Radar data for this area during a 10-day period around the accident indicated a heavy volume of VFR traffic below the Class C floor and several occasions of traffic within about 1500 feet horizontally and 200 feet vertically of each other.

Canadian Aviation Regulations concerning collision avoidance and right-of-way are premised on the principle of see-and-avoid. A pilot's ability to visually detect another aircraft is affected by many factors, including physiological limitations of the human visual and motor-response systems (see Appendix D), obstructions to field of view, aircraft conspicuity, pilot scanning techniques, workload, and alerting to the presence of another aircraft. There is considerable guidance and research material on this subject (see Appendix F for endnotes), salient aspects of which are as follows:

- Conspicuity characteristics
 - Specific paint schemes and patterns may have an advantage in certain conditions but none has an overall advantage over another.^{i, ii, iii}
 - Anti-collision/strobe lights do not have a significant effect in bright daylight.^{iv}
 - Landing lights are useful when the opposing aeroplane is in the direct beam.^v
- Pilot scanning technique
 - The United States Federal Aviation Administration (FAA) recommends that pilots spend 75 per cent of the time scanning a 180° by 30° field of view outside the cockpit.
 - Estimates vary from 54 seconds to 9 minutes to perform the scan.
 - A total of 12.5 seconds is required after first detection for pilot recognition and reaction to avert a collision.
 - In practice, pilots spend 33 per cent of the time scanning outside mainly within 10° of the direction of flight.^{vi}

- Effect of traffic alerting
 - Proportion of time spent scanning outside the cockpit tends to increase.
 - Attention is focussed on known location of conflict.
 - Probability and range of detection increase.

- Probability of detection for this collision geometry and closure rate
 - Maximum discernable range for 6/6 visual acuity: 8.5 km.
 - Earliest likely detection range and time: 3.2 km, 28 seconds.^{vii}
 - Probability of detection for 33 per cent outside scan time: 25 per cent.

TSB records indicate that 16 mid-air collisions occurred in Canada during the preceding 10-year period resulting in 27 fatalities and 5 serious injuries. Of these accidents, 4 involved some form of formation flight or gliders operating in thermals, and the remainder involved aircraft that were not associated with each other. None were within Class D or higher airspace, and none occurred under the control of an ATC unit or while receiving radar surveillance services commonly known as flight following. A total of 6 accidents occurred within the traffic zone of an uncontrolled airport and 6 involved flight beneath controlled airspace associated with a major airport.

One of these occurrences led to a Transport Canada safety review in 2001-2002 of VFR operations in the vicinity of Toronto, Ontario,¹ significant aspects of which are as follows:

- Routing restrictions and confined vertical dimensions contribute to traffic congestion.

- Two system deficiencies were identified concerning availability and quality of aeronautical information and lack of standard operating procedures for VFR operations.

- A number of risk scenarios were identified in which a mid-air collision was a potential outcome that was considered unlikely within the five-year time horizon of the study.

- Several recommendations were made to address the deficiencies and risks.

There has been little progress in implementing the recommendations.

Another of the occurrences took place approximately 5 miles west of the location of this accident and in similar weather conditions. It involved a Cessna 172 aeroplane on an instructional flight and an ultralight aeroplane on a pleasure flight. The right main wheel of the Cessna 172 rolled along the top surface of the left wing of the ultralight. The ultralight was damaged but was able to land safely. The Cessna 172 was undamaged. Neither aeroplane saw the other before the collision.

¹ Transport Canada, TP 13796E, *Safety Review of VFR Operations within the Greater Toronto Area, Final Report, July 2000-April 2001*, October 2004.

There is also a history of occurrences in which there was a risk of collision between commercial air traffic on approach to Hamilton, Ontario, and glider activity in Class E airspace. Gliders have an exemption from the requirement to carry transponders, making them invisible to ATC and the TCAS. Transport Canada found that these occurrences also indicate problems with respect to airspace structure, classification, and ATC operating procedures in airspace adjacent to Toronto Class C airspace.²

According to international agreement,³ regardless of the type of flight plan, pilots are responsible for averting collisions when in visual flight conditions, in accordance with the principle of see-and-avoid. Flights operating under instrument flight rules (IFR) are separated by ATC from other known air traffic. VFR aircraft may also receive traffic advisories from ATC. Most large commercial aircraft are required to be equipped with a TCAS, which provides an automated traffic alert and resolution advisory based on automated exchange of transponder information between the two aircraft. There are some proximity alerting devices available for light aircraft that depend on receiving transponder signals from the other aircraft. The above-mentioned systems at present depend on aircraft being equipped with a transponder. Without a transponder, aircraft are invisible to ATC and TCAS devices. Cost, weight, and power consumption have hindered the fitting of transponders in many light aircraft and gliders.

The NAV CANADA concept⁴ for future air traffic management (ATM), consistent with international plans in the International Civil Aviation Organization (ICAO), includes introducing automatic dependent surveillance broadcast (ADS-B) and ultimately replacing surveillance radar systems when they reach the end of their useful life, which is foreseen to be 10 plus years in the future. Aircraft equipped with ADS-B transmit a position derived from the Global Navigation Satellite System (GNSS) to receivers on the ground and on suitably equipped aircraft. The result is radar-like and TCAS-like capability. The ADS-B is expected to facilitate low-cost technology to provide enhanced collision-avoidance capability for light aircraft.

A number of international studies (see Appendix F) have addressed the overall issue of risk of collision and effectiveness of the see-and-avoid principle. All acknowledged the underlying physiological limitations at play and that, when mid-air collisions occur, "failure to see-and-avoid is due almost entirely to the failure to see."⁵ One study stated that "our data

² Letter from M. Preuss, Director General, Civil Aviation, Transport Canada, to K. McKenzie, Vice President, Operational Development, Westjet, TC file A 5400/1/RDIMS 1962111, dated 03 August 2006.

³ International Civil Aviation Organization, Annex 2 to the Convention on International Civil Aviation, *Rules of the Air*.

⁴ NAV CANADA, *Air Navigation System Plan*, January 2007.

⁵ W. Graham, *See and Avoid/Cockpit Visibility*, FAA Report DOT/FAA/CT-TN89/18, October 1989.

suggest that the relatively low (though unacceptable) rate of mid-air collisions in general aviation aircraft not equipped with TCAS is as much a function of the 'big sky' as it is of effective visual scanning."^{viii} Specific results relevant to this occurrence are as follows:

- A French study^{ix} of mid-air collisions in a 10-year period found that the see-and-avoid principle was becoming no longer adequate as the sole means of averting collisions.
- An Australian study^x concluded that the see-and-avoid principle, in the absence of traffic alerts, has serious limitations and that the historically small number of mid-air collisions is as much due to low traffic density and chance as it is to the successful operation of see-and-avoid. The most effective response to the many flaws of see-and-avoid is to minimize the reliance on it.
- A German study^{xi} on the detection of gliders and small motorized aircraft found that passive conspicuity measures did not overcome the underlying limitations of the see-and-avoid principle. It recommended further development and promotion of GNSS and Mode S transponder technology, noting that there is already on the market a GNSS-based system that is ADS-B compatible, called FLARM.⁶ That system is in use on gliders and provides collision-avoidance information.
- Eurocontrol^{xii} examined risk of collision scenarios between uncontrolled VFR general aviation aircraft and both other uncontrolled VFR traffic and IFR commercial air traffic and found that see-and-avoid was ineffective as the sole means of averting collisions. It preferred technological solutions, specifically increased use of Mode S transponders to function with secondary surveillance radars (SSRs), aircraft collision-avoidance systems (ACAS)/TCAS, TIS, and ADS-B, and to that end endorsed continued development of the Light Aviation SSR Transponder (LAST) including low-powered variants. It found that systems such as FLARM could reduce the risk of collision between VFR aircraft.
- A British Royal Air Force study^{xiii} into mid-air collisions deemed to be random found that the probability of conflict is proportional to the square of the traffic density and recommended avoiding altitude restrictions that concentrate traffic.

Analysis

There was no indication that crew performance played a role in this accident or that either aeroplane was ill-equipped as to conspicuity devices or that those devices were not used appropriately. A realistic probability of either aeroplane detecting the other was 25 per cent, and without detection, the collision was unavoidable. The two aeroplanes were on a constant collision course; therefore, there was no relative angular movement that could be detected by peripheral vision to aid in detection. There was no other means of alerting either aeroplane as to the presence of the other. ATC does not provide traffic advisories in that airspace and TIS,

⁶ FLARM is a trade name inspired by and derived from "FLight AlaRM." Note that this system is not presently certified for use in Canada or the United States.

which is capable of providing specific alerts and was carried by C-GCHN, depends on a ground radar service that is not available in Canada. The failure of the see-and-avoid principle to avert this collision reflects the residual risk that is inherent in sole reliance on unalerted see-and-avoid.

The probability of two aeroplanes being on a collision course is essentially a function of traffic density, and the risk of collision is proportional to the square of the traffic density. The Class C airspace around Toronto/Lester B. Pearson International Airport naturally concentrates circumnavigating traffic around its periphery. The airspace above the arc between Milton, Ontario, and Caledon also concentrates traffic vertically. The combination of surface elevation of 1400 feet, flight at or above 1000 feet agl, and a Class C floor of 2500 feet results in all traffic being concentrated vertically at the single altitude of 2400 feet.

It is unavoidable that Class C airspace results in concentration of circumnavigating traffic around its periphery and this has proven to be a factor statistically in one-half of the collisions that have taken place between non-associated aircraft. Risk of collision can be reduced by dispersing traffic laterally, such as building a VFR route structure with lateral separation between opposite-direction traffic. Such a routing structure would have to be clearly depicted on the VFR terminal area (VTA) chart. However, this structure would not eliminate conflict between aircraft on intersecting tracks, as in this occurrence.

Reduction to the risk of collision between aircraft on intersecting tracks requires that traffic be dispersed vertically. Having 2000 feet of vertical airspace between terrain and the Class C floor rather than 1000 feet at the location of the collision would provide a vertical space of 1000 feet rather than the 100-foot space that existed in this case, reducing the likelihood of a collision. The risk could be reduced further by publishing routes and, where applicable, specific altitudes, in a form that is readily available to VFR pilots.

Measures such as improving aircraft conspicuity, pilot scanning technique, and pilot traffic awareness can reduce risk, but they do not overcome the underlying physiological limitations that create the residual risk associated with unalerted see-and-avoid. There is only limited potential to further reduce risk by fine-tuning the unalerted see-and-avoid concept, and such an approach does little to address the risk of collision between VFR light aircraft and IFR commercial traffic in congested areas.

A meaningful improvement to the ability to see-and-avoid between uncontrolled VFR aircraft requires a practicable, affordable method of alerting pilots to the proximity of conflicting traffic. Reduction of conflicts between VFR aircraft and IFR traffic depends on making aircraft that are presently not transponder-equipped visible to ATC or to the IFR traffic.

Recent developments in Europe, specifically with respect to low-cost, low-power, lightweight LAST technology and collision-protection systems such as FLARM, which are compatible with ADS-B, indicate that technological solutions are emerging that can accomplish both of these objectives. These systems are not yet integrated into airworthiness and airspace standards or universally accepted by user communities. Taking into account the drawbacks of existing transponders due to cost, weight and power consumption, and the foreseeable evolution of

ATM from a radar environment to ADS-B, these new systems offer a means to reduce the risk of mid-air collisions in the future provided that they are integrated into the Canadian regulatory, airworthiness, airspace and navigation framework and supported by general aviation.

Findings as to Causes and Contributing Factors

1. Toronto airspace design provides only limited vertical space beneath Class C airspace northwest of Toronto. Consequently, both aeroplanes were at the same altitude when their tracks intersected, and they collided.
2. There are inherent limitations and residual risk associated with the see-and-avoid principle; as a result, neither aeroplane saw the other in time to avert a mid-air collision.

Finding as to Risk

1. There is a high residual risk of failure inherently associated with the unalerted see-and-avoid principle as the sole defence against mid-air collision in congested airspace.

Other Findings

1. A technological means of alerting pilots to potential conflicts would augment the current see-and-avoid approach to averting mid-air collisions.
2. Canadian air traffic control radars do not support traffic information service (TIS); therefore, aircraft equipped with TIS cannot obtain traffic advisory information.
3. Light aircraft in Canada are not required to carry traffic alert and collision-avoidance system (TCAS) or any other form of traffic alerting system.
4. As a result of technological advances, practicable light aircraft/glider collision warning devices and secondary surveillance radar (SSR) transponders are being developed.
5. There has been little progress in implementing recommendations made by a safety review of visual flight rules operations in Toronto airspace following a previous mid-air collision.

Safety Action

Action Taken

NAV CANADA

NAV CANADA has taken the following actions since this accident, some of which are within the framework of a level of service review of the Montréal-Toronto-Windsor airspace corridor:

- In addition to the Claremont training area depictions, the latest Toronto area visual flight rules (VFR) charts (June 2007) have additional symbols depicting current parachute, ultralight, and flight training areas.
- The Toronto VFR terminal area (VTA) chart (July 2007) contains a new depiction to illustrate the final approach areas for the instrument flight rules (IFR) approaches serving Hamilton with a cautionary note that pilots should be particularly vigilant in those areas for IFR aircraft on approach. The next cycle of the *Canada Flight Supplement* (CFS) will contain a number of these enhancements as well.
- On 05 July 2007, the Class E airspace above 6500 feet within 65 nm of Toronto was designated as mandatory transponder airspace.
- Through 2006-2007, NAV CANADA, in conjunction with Transport Canada, has continued to provide briefing/information sessions to VFR pilots about operations in the Toronto area.
- Through the Airspace and Services reviews consultative workgroups, NAV CANADA continues to facilitate a dialogue on what types of VFR routes and information would best serve the VFR community, including discussion about the information contained on the back of United States VTA charts, common area frequencies, publication of VFR practice areas and transition routes.
- A comprehensive flight planning webpage has been set up, including aerodrome diagrams and other flight planning products, ensuring that pilots have free access to comprehensive and up-to-date aeronautical data.
- An Airspace and Services review has been initiated in the Montréal-Toronto-Windsor corridor.

Brampton Flying Club

The Brampton Flying Club has taken the following safety actions:

- A pulse light system has been installed in all nine Cessna 172s and one Piper Seminole of the Brampton Flying Club fleet to enhance visibility to other aircraft. The remainder of the fleet will also be fitted with pulse lights.

- The Brampton Flying Club has met with NAV CANADA and requested a modest raising of the floor of Class C airspace to the north and west of the Brampton Airport and that the practice area be identified in a manner similar to the Claremont training area on the Toronto VTA and VFR navigation charts (VNC) and in the CFS.

Action Required

Vertical Structure of Airspace

Research has shown that the probability of two aircraft being on a collision course is essentially a function of traffic density, and the risk of collision is proportional to the square of this density. Measures such as improving aircraft conspicuity, pilot scanning technique, and pilot traffic awareness can reduce risk, but they do not overcome the underlying physiological limitations that create the residual risk associated with unalerted see-and-avoid.

The current design of Toronto airspace in the vicinity where this accident occurred results in a concentration of traffic in a very small altitude band, immediately below the floor of Class C airspace, and immediately outside the radius at which the floor of Class C airspace steps down toward the Toronto/Lester B. Pearson International Airport. The combination of a ground elevation of 1400 feet above sea level (asl), flight at or above 1000 feet above ground level (agl), and a Class C floor of 2500 feet asl results in all traffic being concentrated vertically at the single altitude of 2400 feet asl. Changing the vertical structure of the airspace is one way of reducing this traffic concentration.

Radar data reviewed for this area during a 10-day period around the accident indicated a heavy volume of VFR traffic below the Class C floor, and several occasions where aircraft were within about 1500 feet horizontally and 200 feet vertically of each other. In this and other congested airspaces, it has been shown that the see-and-avoid principle for VFR aircraft is not always sufficient to ensure the safety of flight. Therefore, there continues to be a high risk of a mid-air collision between aircraft operating under the VFR principle in that airspace.

Therefore, the Board recommends that:

The Department of Transport, in coordination with NAV CANADA, take steps to substantially reduce the risk of collision between visual flight rules aircraft operating in Class E airspace surrounding the Toronto/Lester B. Pearson International Airport.

A08-03

Safety Concern

Collision-Protection Systems

At the present time, a large number of VFR-only aircraft are not equipped with Mode C transponders, devices that can alert pilots of other aircraft in their vicinity. Furthermore, the lack of other, available, and installed technological methods of alerting VFR pilots to the

presence of other aircraft increases the risk of a mid-air collision, especially in congested airspace. A meaningful improvement to the ability to see-and-avoid other VFR aircraft requires a practicable, affordable method of alerting pilots to the proximity of conflicting traffic.

Recent developments in Europe, specifically with respect to low-cost, low-power, lightweight Light Aviation SSR [secondary surveillance radar] Transponder (LAST) technology and collision-protection systems such as FLARM that are compatible with automatic dependent surveillance broadcast (ADS-B), indicate that technological solutions are emerging that can accomplish both of these objectives. These new systems offer a means to reduce the risk of future mid-air collisions, provided they are integrated into the Canadian regulatory, airworthiness, airspace and navigation framework, and supported by general aviation.

Aircraft operating under VFR in congested airspace using solely the see-and-avoid principle as a means of avoiding one another run an increased risk of collision, as this and other mid-air accidents have demonstrated. This single point of defence has shown that it is not sufficient to ensure safety; however, the Board believes that emerging technology that may be an affordable option to reduce this risk merits a serious look.

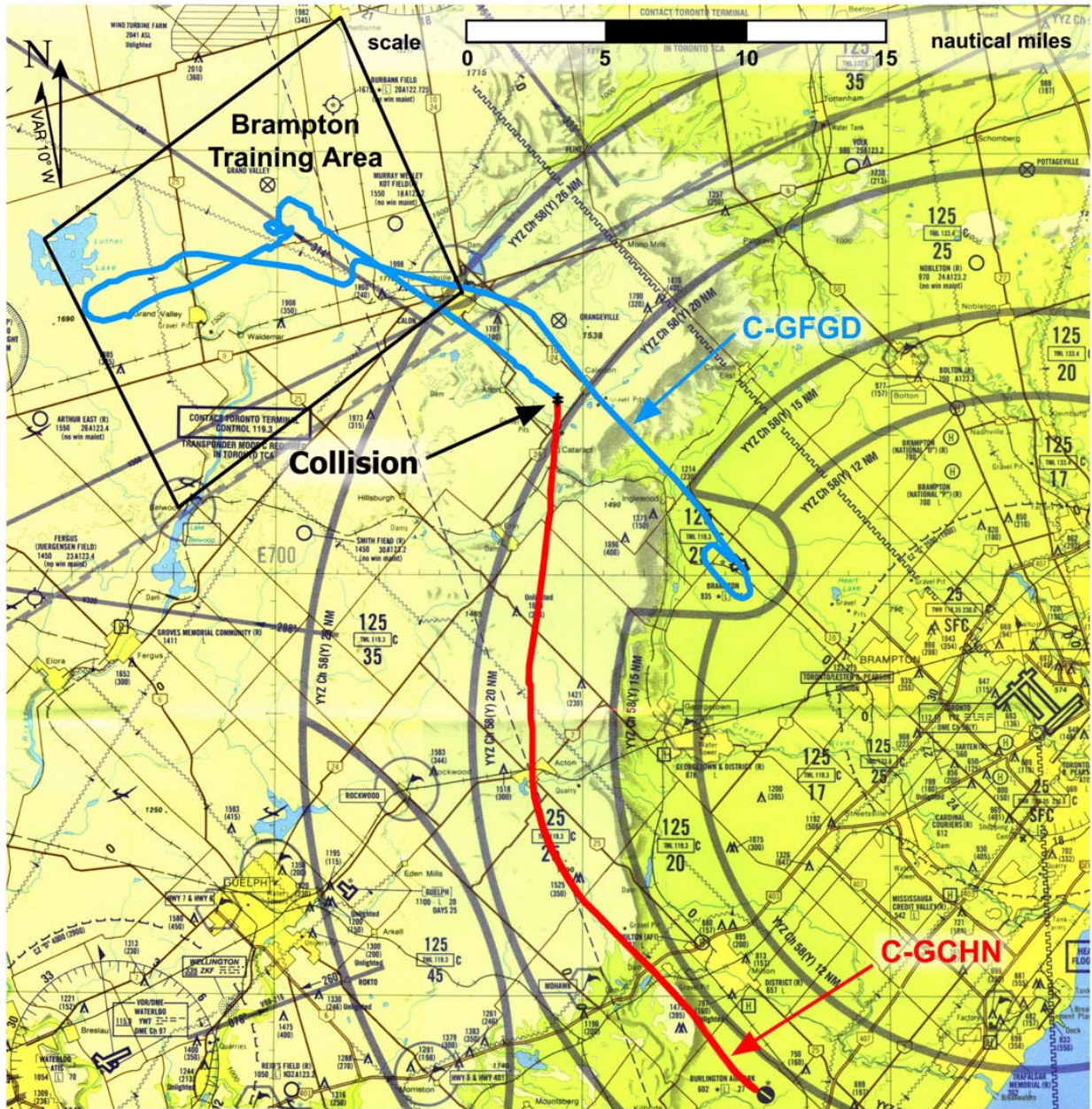
The Board is concerned that, until technological solutions such as on-board collision-protection systems are mandated, a significant risk of collision between VFR aircraft will continue to exist in congested, high-density airspace areas in Canada. The Board notes that the risk of collision will increase as this traffic continues to grow, and see-and-avoid remains the primary means of defence. In addition, the Board recognizes that technological innovation is creating potential solutions that are both viable and economical.

The Board appreciates that Transport Canada must examine all potential solutions before it can decide how best to recommend or mandate the adoption of one or more systems. On this basis, the Board requests that Transport Canada take a lead role, in cooperation with industry, in examining technological solutions, with the eventual aim of broad-scale adoption.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 20 May 2008.

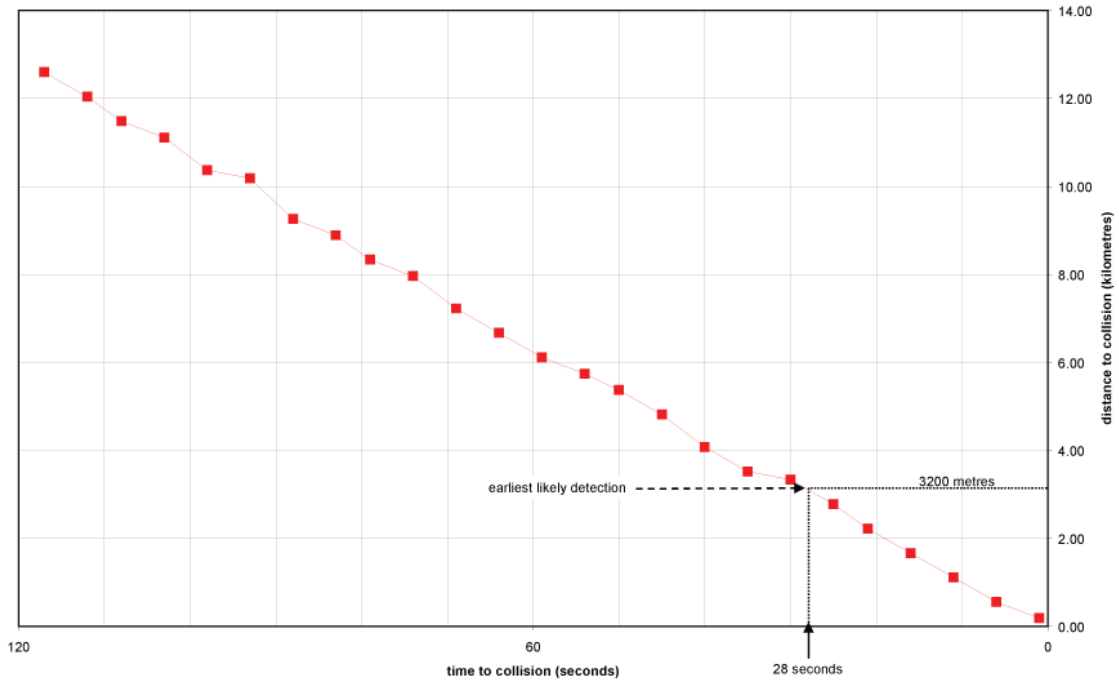
Visit the Transportation Safety Board's Web site (www.tsb.gc.ca) for information about the Transportation Safety Board and its products and services. There you will also find links to other safety organizations and related sites.

Appendix A – Aeroplane Flight Paths

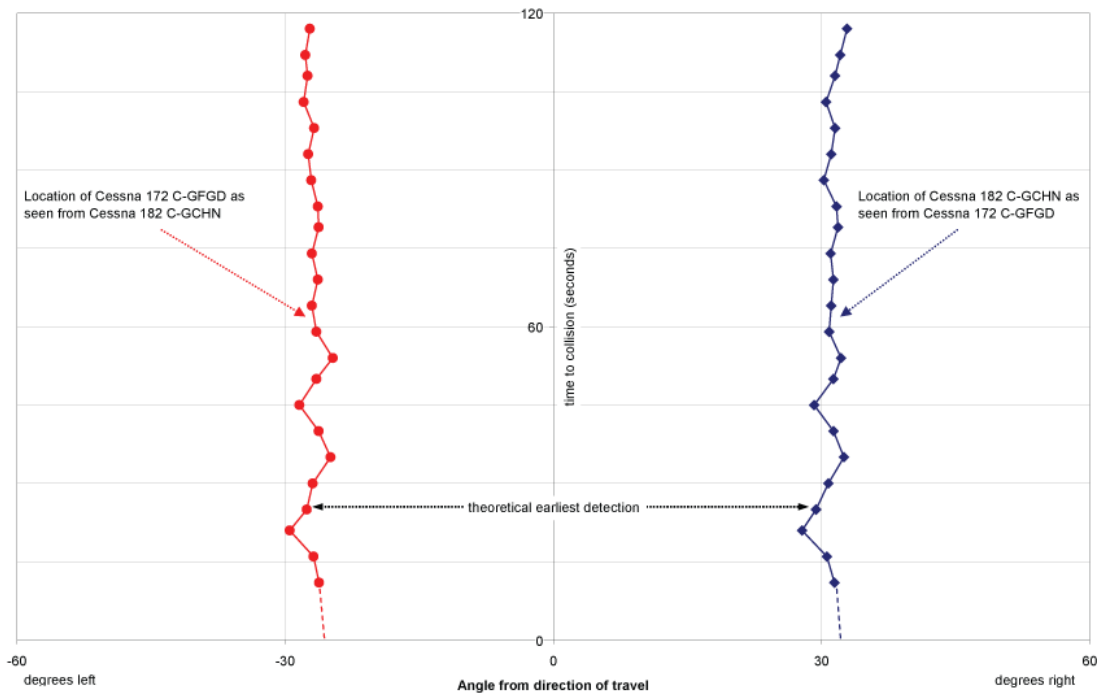


Appendix B – Collision Geometry and Timing

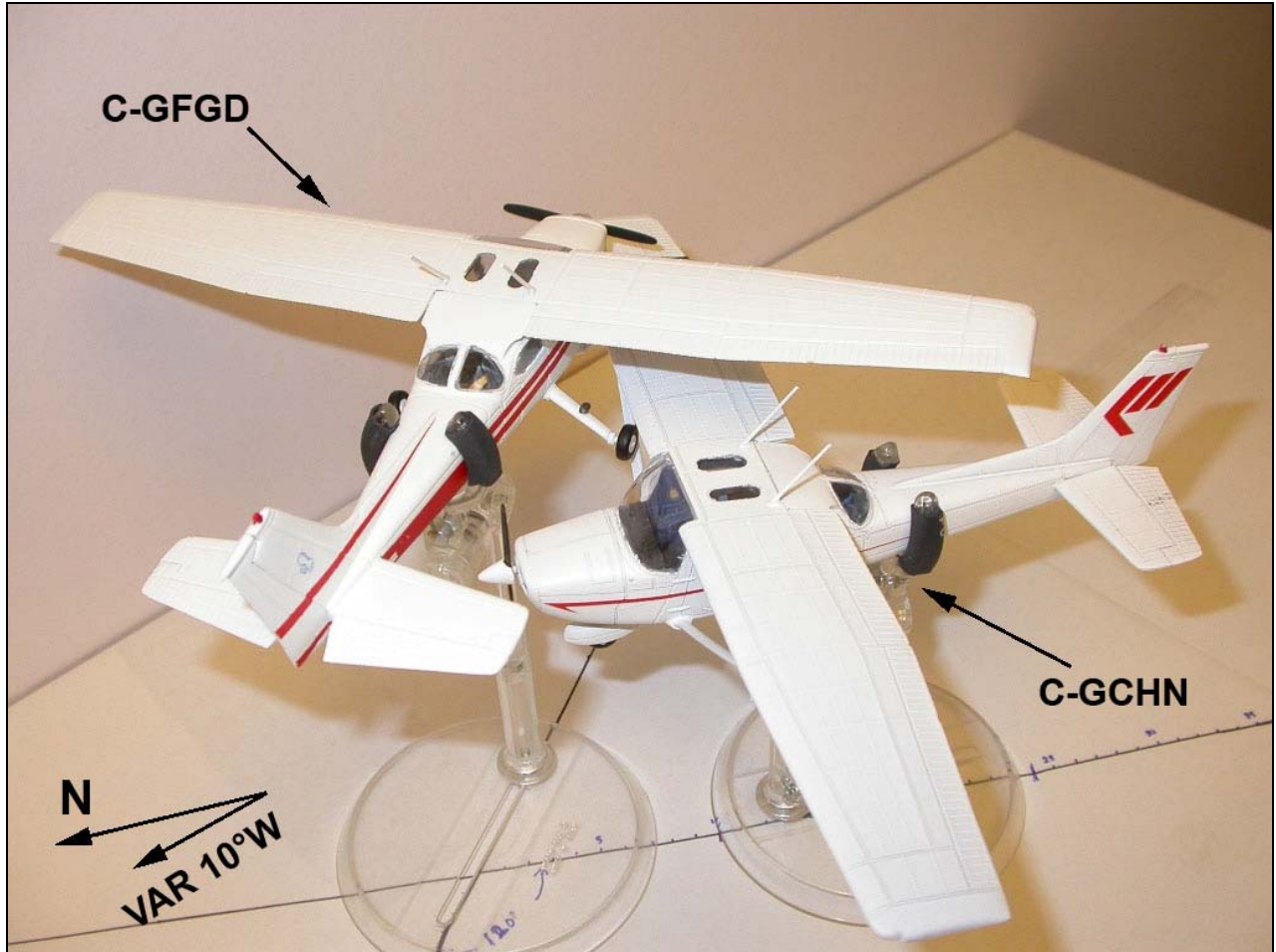
Distance Between Aircraft During Last Two Minutes Before Collision



Location of Conflicting Aircraft During Last Two Minutes Before Collision



Appendix C – Mock-up of Positions at Collision



Appendix D – Field of View for the Crew from Each Aeroplane

		Field of View ⁷ (Degrees from Straight Ahead)				Position of Other Aeroplane	Position of Sun
		Left	Right	Up	Down		
Cessna 172P C-GFGD	Left seat (student)	52°	85°	43°	11°	~30° right of track 1 to 2° below horizon (aeroplane descending at an angle of ~1 to 2°)	~60° right of track 63° above horizon
	Right seat (instructor)	85°	52°	43°	11°		
Cessna 182T C-GCHN	Left seat (pilot)	55°	76°	51°	8°	~30° left of track 1 to 2° above horizon	~180° to track (directly behind aeroplane) 63° above horizon

⁷ Field of view is from the design eye position for each crew member (source: Cessna Aircraft Company).

Appendix E – Physiological Limitations of the Human Eye

General

The human eye receives information about the movement, shape, and colour of the objects we see. That information falls onto the retina (the inner layer at the back of the eye), which contains millions of light-sensitive receptor cells, mainly cones and rods. Cones are stimulated by bright light, provide colour perception, and are concentrated in the fovea (the highly sensitive central area of the retina), which is about 2° wide. Rods respond to darkness, faint light, shape, and movement and are more numerous than cones.

Light entering the eye focuses directly on the fovea, making the fovea the site of greatest visual acuity and providing the ability to distinguish fine details. The optic nerve then relays this visual information, in the form of electrical impulses, to the brain, which processes the impulses into images.

Blind Spot

The optic nerve contains no light-sensitive receptor cells. A blind spot therefore occurs where the optic nerve attaches to the retina. This blind spot is about 5° to 10° wide and is normally compensated for by the other eye. Even when we look at an object with one eye closed, the image appears to be complete because the brain fills in a background of colour and texture to hide the blind spot. However, an object the size of a small aeroplane at a distance of 600 feet could be completely eliminated by this blind spot.

Blind spots can lead to serious consequences for pilots, including collisions. For example, if one eye were to be shielded by an obstruction, such as a windshield pillar, while the image of the potential conflict falls into the blind spot of the eye seeing past the obstruction, the pilot would not see the potential conflict and might divert attention elsewhere. The problem can be resolved by the pilot moving his or her head, but because of the constant relative bearing effect, the pilot still may not see the other aircraft.

Visual Acuity

Relative motion is important for detecting other aircraft because the retina, in particular the fovea, is especially sensitive to small movements. The retina is not equally sensitive over its whole surface; even at small angular departures from the fovea, visual acuity diminishes significantly. For example, the acuity at 5° to the fovea is only one-quarter that at the fovea.⁸ Consequently, a pilot visually searching for a small target is unlikely to see it if the target does not fall on the fovea, especially if the target has no relative movement.

⁸ Bureau of Air Safety Investigation, Australia, "Visual Acuity," *See and Avoid*, 1998.

For aircraft on a collision course, the apparent size of the oncoming aircraft roughly doubles with each halving of the distance apart.⁹ For example, with a closing speed of 180 knots, two general aviation light aircraft, 40 seconds away from impact, will be 2 nm apart; to the pilot, the target size is only 0.25° wide. At 10 seconds to impact, the distance between the aircraft is now 0.5 nm, and the target size is only 1° wide. In other words, the image size of the oncoming aircraft remains extremely small and almost impossible to detect until about 5 seconds to impact, when the image is about 2° wide.

Empty-Field Myopia

In the absence of a visual stimulus, such as empty airspace, the eye muscles relax, preventing the lens from focusing. This presents a problem for a pilot who is attempting to scan for traffic in clear, featureless sky. Because the eye cannot properly focus on empty space, vision becomes unfocused or blurred. This phenomenon hinders effective search and detection.¹⁰

Saccadic Eye Movements

When the eyes are not tracking a moving target, they shift in saccades (a series of jerky movements). As a result, aircrew cannot make voluntary, smooth eye movements while scanning featureless airspace. Research shows that saccadic eye movements decrease visual acuity significantly, leaving large gaps in the distant field of vision.¹¹

Binocular Vision

The effectiveness of target detection depends, in part, on restrictions in the visual field. In an aircraft, the most common restriction is the visual boundary created by the overall structure of the cockpit. The visual field of each eye overlaps with that of the other eye, providing us with binocular vision and enabling depth perception.¹²

⁹ Bureau of Air Safety Investigation, Australia, "Time, Distance and Size," *See and Avoid*, 1998.

¹⁰ S.S. Krause, "Collision Avoidance Must Go Beyond 'See and Avoid' to 'Search and Detect'," *Flight Safety Digest*, Vol. 16, No. 5, May 1997, p. 3.

¹¹ Krause, p. 3.

¹² Krause, p. 4.

The restricted visual field of the cockpit can interfere with a pilot's ability to detect targets. The cockpit layout creates monocular visual borders (areas where an object can only be seen with one eye), thereby diluting visual acuity and inducing the pilot to concentrate searching near the centre of the binocular field (directly ahead).¹³ A typical windshield, for example, is divided by support posts, which create monocular visual borders. Coupled with the natural blind spot limitation of the eye, obstructions such as cockpit windshields, supports, posts, and passengers' heads represent serious challenges for the pilot to visually detect conflicting traffic.

¹³

Krause, p. 5.

Appendix F – Bibliography/References

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