December 20, 2021

Require Carbon Monoxide Detectors in Certain General Aviation Aircraft

Introduction

The National Transportation Safety Board (NTSB) is providing the following information to urge the Federal Aviation Administration (FAA) to take action on this safety recommendation. It is derived from previous investigations and reports of aircraft accidents in which undetected carbon monoxide (CO) poisoning led to pilot impairment and subsequent fatal or serious injuries due to crashes.[1] In each of these accidents, the pilot was not alerted to CO entering the cabin in enough time to counteract the effects of CO poisoning. The NTSB is issuing one safety recommendation to the FAA and one recommendation to pilot industry groups.

Background and Analysis

In many airplanes with reciprocating engines, a defect, leak, or failure in the aircraft's exhaust pipes, muffler, or heat transfer system can introduce CO into the enclosed cabin that can go unnoticed by pilots or passengers.[2] For example, on January 6, 2020, about 1415 eastern standard time, a Cessna 172H, N1612F, was destroyed when it impacted terrain near Newborn, Georgia, and the pilot died.[3] Toxicology testing of the pilot's blood indicated an impairing level of CO. Examination of the two muffler assemblies revealed holes and wall thickness loss around the right muffler body, which likely introduced CO into the cabin. The NTSB

[1] The appendix at the end of this report contains a list of investigations that support these recommendations. Visit ntsb.gov to find additional information in the public docket for each NTSB accident investigation. Use the CAROL Query to search safety recommendations and investigations.

[2] CO is a colorless, odorless, and tasteless gas that is a byproduct of the incomplete combustion of carbon-containing materials, including the fuel used to power aircraft engines and heating systems.

[3] For more information about this accident, see case number ERA20FA068 at the NTSB's website.

determined the probable cause of the accident was pilot incapacitation due to CO poisoning but was unable to determine whether the airplane had a CO detector due to the postaccident fire damage.

Symptoms of CO inhalation include headaches, drowsiness, nausea, or shortness of breath. If a pilot does not quickly recognize these early symptoms, which are often not specific enough to be recognized as CO poisoning, continued exposure can lead to impaired judgment and decreased ability to control the aircraft. Longer exposure or higher blood concentration levels can be incapacitating and can lead to unconsciousness, coma, and death. For instance, toxicology testing following a November 9, 2018, accident involving a Piper PA28-236, N91770, indicated that all four occupants had inhaled enough CO to result in confusion, seizures, or loss of consciousness.[4] The airplane, which was not equipped with a CO detector, was destroyed when it collided with terrain near Guthrie Center, Iowa, and the pilot and three passengers were fatally injured. The NTSB determined the probable cause of the accident was pilot incapacitation due to CO poisoning.

A review of NTSB reports between 1982 and 2020 identified 31 accidents attributed to CO poisoning (see the appendix for a list of these accidents). The data show that 77% of those accidents were fatal and led to 42 fatalities and 4 serious injuries. CO detectors were not found or reported in 30 of those accident reports. Although these accidents can be more prevalent in colder months when pilots are more likely to use aircraft heating systems, accidents related to CO poisoning happen throughout the year; of the 31 accidents between 1982 and 2020, 6 occurred between June and August. The FAA's service difficulty report (SDR) database also showed at least 45 incidents involving a defect, leak, or failure in engine exhaust systems between 1993 and 2020.[5]

Despite the widely recognized dangers of CO poisoning during flight, the FAA does not require CO detectors on enclosed-cabin general aviation aircraft with

[4] For more information about this accident, see case number WPR19FA022 at the NTSB's website.

[5] SDRs are reports submitted by aircraft certificate holders and certificated repair stations that provide the FAA with airworthiness statistical data to identity frequently occurring safety issues that it can address. Although the 45 SDRs did not specifically mention CO poisoning, the defects identified in the reports could have resulted in CO entering the cabin. Additionally, in aircraft that do not have defective exhaust systems, exhaust gases expelled from the engine can potentially enter the cabin through damaged or defective firewall seals, door seals, landing gear compartments, or steering boots. For example, data from the SDR database show at least three incidents between 1998 and 2006 where such failures allowed CO to enter the cabin. Additionally, because Title 14 *Code of Federal Regulations* Part 91 operators are not required to submit SDRs after each incident, the number of incidents is likely higher.

reciprocating engines. The NTSB previously addressed the need for CO detectors on aircraft after a 2004 review of accidents found CO poisoning from exhaust system failure to be an important issue for general aviation aircraft. As a result, the NTSB issued four safety recommendations to the FAA (A-04-25 through -28) to address the dangers of CO poisoning in general aviation aircraft cabins. Safety Recommendation A-04-28 specifically asked the FAA to require the installation of CO detectors that quickly and distinctly alert pilots to the presence of CO in all single-engine, reciprocating powered airplanes with forward-mounted engines and enclosed cockpits that are already equipped with any airplane system needed for the operation of such a CO detector.

The FAA's response to Safety Recommendation A-04-28 stated that it would not require the use of CO detection devices because CO poisoning is due to the failure of an exhaust system, and, therefore, the lack of a CO detector on its own does not constitute an unsafe condition. The FAA's response also pointed to its actions in response to Safety Recommendations A-04-25 through -27, which included:[6]

- Conducting research into CO poisoning detection technology.
- Reviewing international standards for detectors.
- Updating Technical Standard Order (TSO) C48, "Carbon Monoxide Detector Instruments," to include the most recent version of the Society of Automotive Engineers Aerospace Standard 412 Revision B (AS412B), "Carbon Monoxide Detector Instruments" as minimum standards for CO detector applications.[7]

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[6] Safety Recommendation A-04-25 asked the FAA to evaluate inspection methods for exhaust systems and establish a replacement interval. In response, the FAA enhanced previously recommended exhaust system inspection standards, such as pressure testing rather than visual inspections, and recommended replacing mufflers at 1,000 service hours. However, the FAA did not require those inspection standards or the replacement frequency; the NTSB found the FAA's actions only partially responsive and classified this recommendation "Closed—Unacceptable Action" on July 5, 2011. Safety Recommendation A-04-26 asked the FAA to evaluate CO detector technology for use in general aviation airplanes, and Safety Recommendation A-04-27 asked the FAA to develop specific standards to ensure any detection device used in general aviation aircraft quickly and distinctly alerts the user to the presence of CO in the cockpit before the CO reaches a level that would impair a pilot's ability to safely operate an aircraft. As a result of the FAA's action, the NTSB classified Safety Recommendations A-04-26 and -27 "Closed—Acceptable Action" on July 5, 2011.

[7] TSO C48 was updated on May 6, 2009, to C48A and outlines the process by which a manufacturer applies for a TSO authorization or letter of design approval for a CO detector and requires the minimum standards of AS412B for TSO authorization.

- Publishing Special Airworthiness Information Bulletin CE-10-19 R1, "Engine Exhaust and Carbon Monoxide Detectors."

The special airworthiness information bulletin advised all owners and operators of the recommended use of a CO detector and identified recommended actions to detect CO leaks during 100-hour and annual inspections. Because the FAA did not require CO detectors in affected airplanes as recommended, the NTSB classified Safety Recommendation A-04-28 "Closed—Unacceptable Action" on July 5, 2011.

In a 2009 report on CO detectors (produced as part of the FAA's research in response to Safety Recommendation A-04-26), the FAA stated that its recommended (not required) exhaust system inspection standards and muffler replacement time frames would prevent many instances of CO poisoning.[8] However, subsequent accidents show that the FAA's recommended inspection and muffler replacement guidelines are inadequate to protect pilots against the hazards of CO poisoning. As shown in the appendix, 9 accidents (which led to 11 fatalities) that identified CO poisoning have been investigated by the NTSB since the FAA's 2010 recommendations for enhanced exhaust system inspection standards and replacing mufflers at 1,000 service hours. However, because toxicology testing for CO poisoning is generally only performed as part of the investigation of fatal accidents when a suitable specimen is available, the number of accidents due to CO poisoning may be higher.

In accidents since the FAA's recommendations in 2010, the NTSB found that maintenance personnel have likely missed exhaust system failures during inspections and that mufflers have failed in substantially fewer than 1,000 service hours. For example, the investigation of a fatal November 4, 2019, accident found that one of the airplane's two mufflers, which was replaced 742.9 flight hours before the accident flight, had corroded and that the muffler's walls were thin and had pin holes.[9] At the airplane's last annual inspection, less than 15 flight hours before the accident, the exhaust system had not been pressure checked (to identify holes in the muffler) as recommended in the FAA's enhanced inspection standards, but such an inspection was not required.

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[8] FAA. 2009. *Detection and prevention of carbon monoxide exposure in General Aviation Aircraft, Document No. DOT/FAA/AR-09/49*. Accessed online February 25, 2021.

[9] For more information about this accident, see case number ERA20FA031 at the NTSB's website.

In addition, as we noted in support of our 2004 recommendations, pressure testing will not effectively identify a hazardous condition that would lead to CO poisoning until after the cracks and leaks have already perforated the muffler. Although the FAA ultimately recommended the 1,000-hour time frame for replacing mufflers in response to Safety Recommendation A-04-25, the FAA acknowledged the limitations of a single replacement time frame in preventing exhaust system failures due to the design variations of exhaust systems among aircraft manufacturers.[10]

As stated previously, in response to Safety Recommendation A-04-27, the FAA updated TSO C48 to include AS412B. This standard includes some of the most important detector characteristics identified by the FAA in its 2009 research report, such as both aural and visual alarms, and an alarm at specific CO concentrations. The standard also describes specific tests to ensure the detectors' performance under various conditions encountered while flying, including high altitudes, temperature ranges, and other air contaminants. However, the FAA only recommends rather than requires compliance with TSO C48A for CO detectors used in aircraft.

A lack of required minimum standards for CO detectors can result in ineffective alerting if detectors do not meet those standards. For example, out of the 31 accidents attributed to CO poisoning, one involved an airplane that was equipped with a CO detector. However, toxicology testing following the accident indicated that the pilot had inhaled enough CO to have likely resulted in confusion, impaired judgment, and difficulty concentrating.[11] The airplane's CO detector was a type known as a "spot" detector, a passive CO alerting device that turns dark in the presence of CO; it does not include an active aural or visual alert and would therefore not be compliant with TSO C48A. Further, the airplane's CO detector instructions stated to replace it every 90 days, but its opening date was recorded as more than a year before the accident.

Even when functional and used correctly, the effectiveness of spot detectors in a cockpit is limited. These passive detectors require pilots to visually recognize the change in detector color, which can only be accomplished as part of an intentional visual scan—a task that may not be effective during night conditions or possible while impaired by CO poisoning. In addition, spot detectors can be contaminated by

[10] In addition to the 9 accidents involving CO poisoning investigated by the NTSB since 2010, when the FAA recommended a 1,000-hour replacement time frame, SDR data between 2010 and 2020 also show 13 exhaust system failures that allowed or had the potential to allow CO entry into the cabin and involved components that had less than 1,000 service hours, 8 of those with less than 200 service hours.

[11] For more information about this accident, see case number ANC15FA032 at the NTSB's website.

aromatic cleaners, solvents, and other chemicals that are routinely used in aircraft maintenance. The NTSB recognizes that spot detectors can appeal to aircraft owners because they are less expensive than TSO-compliant CO detectors with aural alerts, which must be installed and hardwired to the aircraft. Although the detectors that had the most crucial features identified by the FAA in its 2009 report typically cost thousands of dollars at that time, we note that the price of alerting CO detectors has since decreased.

The NTSB emphasizes that, although potentially more cost-effective, CO detectors that do not meet an aviation-appropriate minimum performance standard to ensure they operate effectively in an aircraft can give pilots a false sense of protection from CO poisoning.[12] When pilots purchase a CO detector that they believe is appropriate for aircraft use and will alert them to the presence of CO, they may rely more on the device rather than being alert to the early symptoms of CO poisoning. If the device is not built to an aviation-appropriate minimum performance standard, it may not appropriately alert the pilot in a timely manner to avoid a crash.

If a minimum performance standard is met and active aural or visual alerting is included, non-TSO-compliant CO detectors could be an effective means of preventing CO poisoning in flight. For example, through the Non-Required Safety Enhancing Equipment (NORSEE) program, the FAA has approved CO detectors that have active aural or visual alerting.[13] CO detectors that adhere to the critical detection, alerting, and altitude requirements of an industry standard such as AS412B would also be effective in flight.[14] Further, some multifunction devices are built with CO detection capabilities. Again, although non-TSO-compliant CO detectors can be more affordable compared to the costs of TSO-compliant detectors, the accuracy and reliability of their alerting capabilities should be the priority. If required, non-TSO-compliant CO detectors that meet an aviation-appropriate minimum performance

[12] Some CO detectors on the market can also be intended for different purposes, such as in mobile homes or recreational vehicles, and may lack the capabilities required to effectively operate in an aircraft.

[13] NORSEE guidelines were developed in response to recommendations from the General Aviation Joint Steering Committee, which is a joint effort by the FAA and industry stakeholders to improve general aviation safety. These guidelines are intended to be "scalable and adjustable to accommodate and encourage the installation of new technology safety enhancements into all aircraft product types" and are approved by the FAA.

[14] The AS412B standard, which was discussed previously in this report, does not require the CO detector to be installed in the aircraft.

standard would be an effective means of preventing CO poisoning in the cabin. However, none of these types of CO detectors are required devices.

In the 17 years since the NTSB issued Safety Recommendations A-04-25 through -28, we have continued to alert pilots and mechanics to the dangers of CO poisoning. In September 2017, the NTSB issued two safety alerts on the dangers of CO poisoning. Safety Alert 69, "Pilots: Prevent Carbon Monoxide Poisoning," suggests, among other things, that pilots install a CO detector and check their aircraft's exhaust system during preflight inspections for cracking or evidence of soot. Safety Alert 70, "Mechanics: Prevent Carbon Monoxide Poisoning," suggests, among other things, that mechanics inspect exhaust systems, vents, and other areas that could introduce CO into the cabin.[15]

In addition, aviation safety agencies in other countries have highlighted the need for active-alerting CO detectors in the cockpit to prevent accidents. The United Kingdom's Air Accidents Investigation Branch (AAIB) investigation of a fatal January 2019 accident determined that the airplane broke up in flight after the pilot's loss of control due to CO poisoning. As a result, the AAIB recommended that the FAA and other civil aviation authorities require piston engine aircraft that may have a risk of CO poisoning to have a CO detector with an active warning to alert pilots to the presence of elevated levels of CO.[16]

The Australian Transport Safety Bureau's investigation of a fatal December 2017 accident determined that the pilot's flying abilities had degraded due to CO poisoning. The airplane was equipped with a CO spot detector, but the Australian Transport Safety Bureau found that it was "likely not effective on the accident flight due to sun bleaching," and a detector with aural or visual alerts would have more effectively alerted the pilot to elevated levels of CO in the cabin.[17]

The presence of CO in an aircraft cabin presents a hazardous condition to pilots. The FAA's current recommended exhaust system inspections and muffler

[15] Safety Alerts 69 and 70 can be accessed online at the NTSB's safety alert web page.

[16] AAIB. 2020. *Report on the accident to Piper PA-46-310P Malibu, N264DB, 22 nm north-north-west of Guernsey on 21 January 2019*. Aircraft Accident Report AAR 1/2020. In July 2020, the FAA responded that it was "evaluating this recommendation," and the AAIB classified the response as "Partially Adequate." March 2021, the FAA responded that it did "not have justification to support mandatory requirements for installed CO detectors in all piston aircraft," but it was exploring options to encourage CO detector use.

[17] Australian Transport Safety Bureau. 2021. *Collision with water involving de Havilland Canada DHC-2, VH-NOO, Jerusalem Bay (Hawkesbury River), New South Wales, on 31 December 2017.* AO-2017-118.

replacement schedules have not prevented fatal aircraft accidents due to CO poisoning. The NTSB is concerned about the continued hazards resulting from CO poisoning because the FAA does not require CO detectors on enclosed-cabin aircraft. The NTSB concludes that use of a functional CO detector to alert a pilot through visual and auditory means to the presence of CO before the pilot's judgment is impaired is necessary to the continued safe operation of the aircraft. The NTSB also concludes that CO detectors that do not meet an aviation-specific minimum performance standard with active aural or visual alerting may not ensure the timely detection of CO by pilots. Therefore, the NTSB recommends that the FAA require that all enclosed-cabin aircraft with reciprocating engines be equipped with a CO detector that complies with an aviation-specific minimum performance standard with active aural or visual alerting.

In addition, the NTSB concludes that, while FAA action is pending, pilot industry groups can quickly and effectively disseminate information to their members and encourage operators to make safety changes to reduce the risks of CO poisoning in flight. Therefore, the NTSB recommends that the Aircraft Owners and Pilots Association and Experimental Aircraft Association inform their members about the dangers of CO poisoning in flight and encourage them to install CO detectors with active aural or visual alerting and proactively ensure thorough exhaust inspection during regular maintenance.

Conclusion

Findings

Use of a functional carbon monoxide (CO) detector to alert a pilot through visual and auditory means to the presence of CO before the pilot's judgment is impaired is necessary to the continued safe operation of the aircraft.

Carbon monoxide (CO) detectors that do not meet an aviation-specific minimum performance standard with active aural or visual alerting may not ensure the timely detection of CO by pilots.

While Federal Aviation Administration action is pending, pilot industry groups can quickly and effectively disseminate information to their members and encourage operators to make safety changes to reduce the risks of CO poisoning in flight.

Recommendations

To the Federal Aviation Administration:

Require that all enclosed-cabin aircraft with reciprocating engines be equipped with a carbon monoxide detector that complies with an aviation-specific minimum performance standard with active aural or visual alerting. (A-22-1)

To the Aircraft Owners and Pilots Association and Experimental Aircraft Association:

Inform your members about the dangers of carbon monoxide (CO) poisoning in flight and encourage them to 1) install CO detectors with active aural or visual alerting and 2) proactively ensure thorough exhaust inspection during regular maintenance. (A-22-2)

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Report Date: December 20, 2021

Appendix

NTSB accidents and incidents involving carbon monoxide (CO) poisoning (1982-2020)[18]

Accident	Date	Was aircraft equipped with a CO detector?	Fatalities and Serious Injuries
Oxnard, CA (LAX82FUQ12)	3/22/1982	Report does not specify	1 fatal
Ramon, NM (FTW83LA156)	3/15/1983	Report does not specify	None
Loris, SC (ATL84FA090)	2/1/1984	Report does not specify	4 fatal
Cumberland, MD (NYC84MA102)	3/5/1984	Report does not specify	3 fatal
Lakeland, FL (MIA88DL001)	4/10/1988	Report does not specify	1 serious
Fowler, CO (DEN90DTE04)	7/22/1990	Report does not specify	2 fatal
Holland, MI (CHI90DEM08)	8/6/1990	Report does not specify	2 fatal
Burns, OR (SEA91FA156)	7/5/1991	Report does not specify	2 fatal
Monte Vista, CO (DEN92FA020)	12/25/1991	Report does not specify	3 fatal
Mt. Gilead, OH (NYC93LA031)	10/31/1992	Report does not specify	1 serious
Kerman, CA (LAX94LA184)	4/7/1994	Report does not specify	1 serious
Pittsburg, KS (CHI96LA101)	3/1/1996	Report does not specify	None
Jeffersonville, IN (CHI96FA322)	8/30/1996	Report does not specify	1 fatal
Alton, NH (IAD97FA043)	1/17/1997	Report does not specify	2 fatal
Fort Lauderdale, FL (MIA97FA070)	1/23/1997	Report does not specify	4 fatal
Cairo, MO (CHI98LA055)	12/6/1997	Report does not specify	None
Faribault, MN (CHI98FA086)	1/26/1998	Report does not specify	2 fatal
Prescott Valley, AZ (LAX00FA213)	6/1/2000	Report does not specify	None
Rolla, MO (CHI01FA052)	12/17/2000	Report does not specify	1 fatal
Oak Hill, FL (ATL02LA035)	1/10/2002	Report does not specify	1 fatal
Herron, WA (SEA04LA050)	2/29/2004	Report does not specify	2 fatal
Portland, OR (SEA05FA090)	4/30/2005	CO detector not found during the investigation	1 fatal
Boerne, TX (CEN14FA024)	10/27/2013	CO detector not found during the investigation	1 fatal
Bethel, AK (ANC15FA032)	5/30/2015	Equipped with a "spot" CO detector, which had likely expired	1 fatal
Ellsworth, NE (CEN16FA130)	3/20/2016	CO detector not found during the investigation	1 fatal
Anchorage, AK (ANC16FA065)	9/10/2016	CO detector not found during the investigation	1 fatal
Ellendale, MN (CEN17LA101)	2/2/2017	Not equipped with CO detector	1 serious
Bowling Green, OH (CEN17FA207)	6/1/2017	CO detector not found during the investigation	1 fatal
Guthrie Center, IA (WPR19FA022)	11/9/2018	Not equipped with CO detector	4 fatal
New Bedford, MA (ERA20FA031)	11/4/2019	Not equipped with a CO detector	1 fatal
Newborn, GA (ERA20FA068)	1/6/2020	CO detector not found in investigation	1 fatal

[18] More information about the accidents in this table is available by searching the CAROL Query.

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