



Aviation Investigation Final Report

Location:	Moncks Corner, South Carolina	Accident Number:	ERA15MA259
Date & Time:	July 7, 2015, 11:00 Local	Registration:	N3601V
Aircraft:	Cessna 150M	Aircraft Damage:	Destroyed
Defining Event:	Midair collision	Injuries:	2 Fatal
Flight Conducted Under:	Part 91: General aviation - Personal		

Analysis

The pilot of the F-16, who was operating on an instrument flight rules (IFR) flight plan, was in contact with air traffic control (ATC) and was provided radar vectors for a practice instrument approach to Charleston Air Force Base/International Airport (CHS), Charleston, South Carolina; the F-16 descended to an altitude of about 1,600 ft mean sea level as instructed by the air traffic controller. Shortly thereafter, the Cessna departed under visual flight rules (VFR) from a nearby nontowered airport; the Cessna pilot was not in contact with ATC, nor was he required to be, and had not requested traffic advisory (flight-following) services. As the Cessna continued its departure climb, the airplanes converged to within about 3.5 nautical miles (nm) laterally and 400 ft vertically, triggering a conflict alert (CA) on the controller's radar display and an aural alarm. About 3 seconds later, the air traffic controller issued a traffic advisory notifying the F-16 pilot of the position, distance, and indicated altitude of the radar target that corresponded to the Cessna, stating that the aircraft type was unknown. When the F-16 pilot replied that he was looking for the traffic, the controller issued a conditional instruction to the F-16 pilot to turn left if he did not see the airplane. The F-16 pilot did not see the airplane and responded, asking "confirm two miles?" The controller responded, "if you don't have that traffic in sight turn left heading 180 immediately." As the controller began this transmission, the F-16 pilot initiated a standard rate (approximately) left turn using the autopilot so that he could continue to visually search for the traffic; however, the airplanes continued to converge and eventually collided about 40 seconds after the controller's traffic advisory notifying the F-16 pilot of traffic. (Figure 1 in the factual report for this accident shows the calculated flight tracks for the Cessna and F-16.)

Air Traffic Controller and F-16 Pilot Performance

During postaccident interviews, the controller reported that when she observed the Cessna's target on her radar display as it departed, she thought that the airplane would remain within its local traffic pattern, which was not the case. Therefore, it was not until the airplanes were within about 3.5 nm and 400 vertical ft of one another that the controller notified the F-16 pilot of the presence of the traffic by issuing the traffic advisory, which was about 3 seconds after the ATC radar CA alarmed. (Federal

Aviation Administration [FAA] Order 7110.65, *Air Traffic Control*, paragraph 2-1-21, "Traffic Advisories," states, in part, that a controller should "Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may diminish to less than the applicable separation minima. Where no separation minima applies, such as for VFR aircraft outside of Class B/Class C airspace, or a TRSA [terminal radar service area], issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it. ...")

When the controller issued the traffic advisory, about 40 seconds before the eventual collision, the F-16 and the Cessna had a closure rate of about 300 knots. If the F-16 pilot had reported the Cessna in sight after the controller's traffic advisory, the controller likely would have directed the F-16 pilot to maintain visual separation, which is a common controller technique to separate aircraft. While the controller tried to ensure separation between the airplanes, her attempt at establishing visual separation at so close a range and with the airplanes converging at such a high rate of speed left few options if visual separation could not be obtained.

The options available to the controller when issuing instructions to the F-16 pilot to avoid the conflict included a turn, climb, some combination thereof, or not issuing an instruction at all. (An instruction to descend was not an option because the F-16 was already at the minimum vectoring altitude for the area.) The controller indicated in a postaccident interview that she chose not to instruct the F-16 to climb because the altitude indicated for the Cessna's radar target was unconfirmed (the Cessna pilot had not contacted ATC). An element informing the controller's decision-making as to which instruction to provide was likely the flow of other traffic into the airport at that time. Arriving aircraft, including the accident F-16, were being sequenced to runway 15 via the final approach course extending from the approach end of the runway. Given the traffic flow, the left turn instruction to the F-16 would have kept the airplane on a heading closer toward, rather than farther from, its destination and would have made returning the F-16 to the intended final approach course much easier. However, the controller's instruction to the F-16 pilot to turn left required the F-16's path to cross in front of the Cessna. Although this decision was not contrary to FAA guidance for air traffic controllers, it was the least conservative decision, as it was most dependent on the F-16 pilot's timely action for its success.

Further, the controller issued the instruction to turn left if the F-16 pilot did not have the Cessna in sight. The F-16 pilot responded to the controller's conditional instruction with a question ("confirm two miles?") that indicated confusion about the distance of the traffic. The F-16 pilot's attempt to visually acquire the Cessna per the controller's conditional instruction likely resulted in a slight delay in his beginning the turn. The collision likely would have been avoided had the F-16 pilot initiated the left turn, as ATC instructed, when he realized that he did not have the traffic in sight. About 7 seconds elapsed between the beginning of the controller's first conditional instruction to turn and the beginning of her subsequent conditional instruction to the F-16 pilot to turn "immediately." Analysis of the radio transmission recordings and the F-16's flight recorder data showed that, as the controller was making the subsequent conditional instruction, the F-16 pilot began turning to the left, which pointed his aircraft toward the Cessna.

Due to the closure rate, the close proximity of the two airplanes, and human cognitive limitations, the controller did not recover from her ineffective visual separation plan, which placed the airplanes in closer proximity to each other, and switch to an alternative method of separation. The controller's best

course of action would have been to instruct the F-16 pilot to turn before the airplanes came into close proximity with each other and preferably in a direction that did not cross in front of the Cessna's path.

In postaccident interviews, the controller stated that when she issued the command to the F-16 pilot to turn left "immediately," she expected that the F-16 pilot would perform a high performance maneuver and that she believed that fighter airplanes could "turn on a dime." The FAA's *Aeronautical Information Manual* (AIM) Pilot-Controller Glossary defines "immediately" as a term used by ATC or pilots "when such action compliance is required to avoid an imminent situation." Further, the AIM states that controllers should use the term "immediately" to "impress urgency of an imminent situation" and that "expeditious compliance by the pilot is expected and necessary for safety." As described above, the F-16 pilot did not meet her expectation that the turn be conducted at a greater-than-standard rate.

The controller's expectation of the F-16 pilot's performance was based on her assumption that a fighter airplane would perform a high performance turn to the heading; however, this expectation of performance was not clearly communicated. Based on the controller's instructions and the actions of the F-16 pilot in response, it is clear that the term "immediately" held different expectations for both parties. Although the controller's use of the term "immediately" was in keeping with FAA guidance, further clarification of her expectation, such as directing the pilot to "expedite the turn," would have removed any ambiguity.

See-and-Avoid Concept

According to 14 *Code of Federal Regulations* 91.113, "Right-of-Way Rules," "when weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft." The concept that pilots are primarily responsible for collision avoidance was similarly stressed in US Air Force training documents. In addition, FAA Advisory Circular (AC) 90-48C, "Pilots' Role in Collision Avoidance," which was in effect at the time of the accident, stated that the see-and-avoid concept requires vigilance at all times by each pilot, regardless of whether the flight is conducted under IFR or VFR. (AC 90-48D replaced AC 90-48C in 2016 and contains the same statement.)

The see-and-avoid concept relies on a pilot to look through the cockpit windows, identify other aircraft, decide if any aircraft are collision threats, and, if necessary, take the appropriate action to avert a collision. There are inherent limitations of this concept, including limitations of the human visual and information processing systems, pilot tasks that compete with the requirement to scan for traffic, the limited field of view from the cockpit, and environmental factors that could diminish the visibility of other aircraft.

Factors Impacting the Pilots' Ability to Detect Other Traffic

The collision occurred in a relatively low-density air traffic environment in visual meteorological conditions (VMC). The Cessna was equipped with an operating transponder and single communication radio but was not equipped with any technologies in the cockpit that display or alert of traffic conflicts, such as traffic advisory systems, traffic alert and collision avoidance systems, or automatic dependent surveillance-broadcast systems. The Cessna had departed from a nontowered airport and was still in close proximity to the airport when the collision occurred. The Cessna pilot had not requested or received flight-following services from ATC at the time of the collision, nor was he required to do so.

Based on his proximity to the departure airport, it is reasonable to expect that the Cessna pilot likely was monitoring that airport's common traffic advisory frequency (CTAF) for awareness of airplanes in the vicinity of the airport, as recommended by the FAA's AIM. Based on statements from the Cessna pilot's flight instructor and from his logbook entries, which both cited past experience communicating with ATC, it is also reasonable to assume that had the collision not occurred, the pilot likely would have contacted ATC at some point during the flight to request flight-following services.

Due to the Cessna's lack of technologies in the cockpit that display or alert of traffic conflicts and the pilot's lack of contact with ATC, his ability to detect other traffic in the area was limited to the see-and-avoid concept. While not required, had the Cessna been equipped with a second communication radio, the pilot could have used it to contact ATC while still monitoring the departure airport's CTAF. Had the Cessna pilot contacted ATC after departing and received ATC services, the controller would have had verification of the Cessna's altitude readout and its route of flight, which would have helped her decision-making process. The controller also could have provided the Cessna pilot awareness of the F-16.

The F-16 was operating under IFR in VMC. The F-16 pilot's ability to detect other traffic was limited to the see-and-avoid concept, supplemented with ATC traffic advisories. While the F-16 pilot could use the airplane's tactical radar system to enhance his awareness of air traffic, it was designed to acquire fast-moving enemy aircraft rather than slow-moving, small aircraft and was thus unable to effectively detect the Cessna. (The radar system did detect a target 20 miles away, which is likely what led the F-16 pilot to question the location of the traffic that the controller had indicated was 2 miles away.) The F-16 was not otherwise equipped with any technologies in the cockpit that display or alert of traffic conflicts. The F-16 pilot did eventually visually acquire the Cessna but only when the airplanes were within about 430 ft of one another, about 1 second before the accident.

A factor that can affect the visibility of traffic in VMC is sun glare, which can prevent a pilot from detecting another aircraft when it is close to the position of the sun in the sky. For the F-16 pilot, the sun would have been behind and to his left as the airplanes approached one another. Although the Cessna pilot would have been heading toward the sun, the sun's calculated position would likely have been above a point obstructed by the Cessna's cabin roof and would not have been visible to the Cessna pilot. Thus, sun glare was not a factor in this accident.

Aircraft Performance and Cockpit Visibility Study

Our aircraft performance and cockpit visibility study showed that, as the accident airplanes were on converging courses, they each would have appeared as small, stationary, or slow-moving objects to the pilots. Given the physiological limitations of vision, both pilots would have had difficulty detecting the other airplane. Specifically, the study showed that the Cessna would have appeared as a relatively small object through the F-16's canopy, slowly moving from the center of the transparent heads-up display (HUD) to the left of the HUD. As the F-16 started the left turn as instructed by the air traffic controller, the Cessna moved back toward the center of the HUD and then off to its right side, where it may have been obscured by the right structural post of the HUD. It was not visible again until about 2 seconds before the collision. (Figures 3a and 5a in the factual report for this accident show the simulated cockpit visibility from the F-16 at 1100:18 and 1100:56, respectively.) The F-16 pilot reported that before the controller alerted him to the presence of traffic, he was actively searching for traffic both visually and using the airplane's targeting radar. He reported that after the controller advised him of traffic, he was

looking "aggressively" to find it. By the time he was able to visually acquire the Cessna, it was too late to avert the collision.

Our investigation could not determine to what extent the Cessna pilot was actively conducting a visual scan for other aircraft. Our aircraft performance and cockpit visibility study showed that the F-16 would have remained as a relatively small and slow-moving object out the Cessna's left window (between the Cessna's 9 and 10 o'clock positions) until less than 5 seconds before the collision. Given the speed of the F-16, the Cessna pilot likely would not have had adequate time to recognize and avoid the impending collision.

Cockpit Display of Traffic Information

Although the Cessna and F-16 pilots were responsible for seeing and avoiding each other, our aircraft performance and cockpit visibility study showed that, due to the physiological limitations of vision and the relative positions of the airplanes, both pilots would have had difficulty detecting the other airplane. Research indicates that any mechanism to augment and focus pilots' visual searches can enhance their ability to visually acquire traffic. (AC 90-48D highlights aircraft systems and technologies available to improve safety and aid in collision avoidance, and our report regarding a midair collision over the Hudson River [AAR-10/05] states that "traffic advisory systems can provide pilots with additional information to facilitate pilot efforts to maintain awareness of and visual contact with nearby aircraft to reduce the likelihood of a collision. ...") One such method to focus a pilot's attention and visual scan is through the use of cockpit displays and aural alerts of potential traffic conflicts. Several technologies can provide this type of alerting by passively observing and/or actively querying traffic. While the accident airplanes were not equipped with these types of systems, their presence in one or both cockpits might have changed the outcome of the event. (The images from our in-cockpit traffic display simulation are representative of the minimum operations specifications contained in RTCA document DO-317B, *Minimum Operational Performance Standards for Aircraft Surveillance Applications System* [dated June 17, 2014], but do not duplicate the implementation or presentation of any particular operational display exactly; the actual images presented to a pilot depend on the range scale and background graphics selected by the pilot.)

Because the Cessna pilot was not in contact with ATC and was relying solely on the see-and-avoid concept, an indication of approaching traffic might have allowed him to visually acquire the F-16 and take action to avoid it. While most systems are limited to aiding pilots in their visual acquisition of a target and do not provide resolution advisories (specific maneuvering instructions intended to avoid the collision), the augmentation of a pilot's situational awareness might allow the pilot to change the flightpath in anticipation of a conflict and, thus, avoid airplanes coming in close proximity to one another. The Cessna pilot might have noted the presence of the F-16 and its level altitude of about 1,600 ft as he continued his departure climb. With this information, the Cessna pilot might have arrested his airplane's climb as he began a visual search, thus creating an additional vertical buffer between his airplane and the approaching F-16.

While the F-16 pilot's visual search was augmented by the controller's traffic advisory, a successful outcome would have depended upon the pilot's visual acquisition of the target airplane in time to take evasive action. Our in-cockpit traffic display simulation showed that the F-16 pilot might have first observed the Cessna when it was about 15 nm away, or nearly 3 minutes before the collision. As the F-16 closed to within 6 nm of the Cessna, or slightly more than 1 minute before the collision, the conflict

might have become even more apparent to the pilot showing that not only were the airplanes in close proximity laterally but also that they were only separated vertically by 600 ft. As the F-16 pilot was beginning his left turn as instructed by ATC, the presence of the Cessna would have been aurally annunciated, and its traffic symbol would have changed from a cyan color to a yellow color. The information presented on the in-cockpit traffic display would have clearly indicated that the airplanes were on a collision course that might not be resolved by a left turn and that the vertical separation between the airplanes had decreased to 300 ft.

Consequently, an in-cockpit traffic display could have helped the F-16 pilot recognize the potential for a collision in advance of the controller's instruction to turn left. The earlier warning also could have provided him additional time to conduct his visual search for the Cessna and potentially take other preemptive action to avoid the collision. Had the F-16 been equipped with a system that was able to provide the pilot with resolution advisories, the F-16 pilot could have taken action in response to that alarm to avoid the collision, even without acquiring the Cessna visually.

Postaccident Actions

In November 2016, we issued safety recommendations to the FAA and Midwest Air Traffic Control, Robinson Aviation, and Serco (companies that operate federal contract towers) to (1) brief all air traffic controllers and their supervisors on the ATC errors in this midair collision and one that occurred on August 16, 2015, near San Diego, California; and (2) include these midair collisions as examples in instructor-led initial and recurrent training for air traffic controllers on controller judgment, vigilance, and/or safety awareness.

In November 2016, we also issued a safety alert titled "Prevent Midair Collisions: Don't Depend on Vision Alone" to inform pilots of the benefits of using technologies that provide traffic displays or alerts in the cockpit to help separate safely. (In May 2015 [revised in December 2015], we issued a safety alert titled "See and Be Seen: Your Life Depends on It" regarding the importance of maintaining adequate visual lookout.)

After the accident, the Cessna's departure airport engaged in several outreach efforts (including posting midair collision avoidance materials locally and having outreach meetings with pilots) to raise awareness regarding midair collisions and encourage contact with ATC. The airport also updated its chart supplement to note the presence of military and other traffic arriving at and departing from CHS.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be: The approach controller's failure to provide an appropriate resolution to the conflict between the F-16 and the Cessna. Contributing to the accident were the inherent limitations of the see-and-avoid concept, resulting in both pilots' inability to take evasive action in time to avert the collision.

Findings

Personnel issues	Decision making/judgment - ATC personnel
Personnel issues	Visual function - Pilot
Personnel issues	Visual function - Pilot of other aircraft

Factual Information

History of Flight

Enroute-climb to cruise	Midair collision (Defining event)
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On July 7, 2015, about 1101 eastern daylight time, a Cessna 150M, N3601V, and a Lockheed Martin F-16CM, operated by the US Air Force (USAF), collided in midair near Moncks Corner, South Carolina. The private pilot and passenger aboard the Cessna died, and the Cessna was destroyed during the collision. The damaged F-16 continued to fly for about 2 1/2 minutes, during which the pilot activated the airplane's ejection system. The F-16 pilot landed safely using a parachute and incurred minor injuries, and the F-16 was destroyed after its subsequent collision with terrain and postimpact fire. Visual meteorological conditions prevailed at the time of the accident. No flight plan was filed for the Cessna, which departed from Berkeley County Airport (MKS), Moncks Corner, South Carolina, about 1057, and was destined for Grand Strand Airport, North Myrtle Beach, South Carolina. The personal flight was conducted under the provisions of 14 Code of Federal Regulations (CFR) Part 91. The F-16 was operating on an instrument flight rules (IFR) flight plan and had departed from Shaw Air Force Base (SSC), Sumter, South Carolina, about 1020.

Air Force F-16

According to the USAF, the F-16 pilot was assigned as pilot-in-command for a single-ship, operational check flight to verify the completion of recent corrective maintenance. The flight itinerary included practice instrument approaches at Myrtle Beach International Airport (MYR), South Carolina, and Charleston Air Force Base/International Airport (CHS), Charleston, South Carolina, before returning to SSC. Since the flight was single ship and single pilot, the pilot performed an individual flight briefing using the personal briefing guide. (The Shaw General Briefing Guide is a local USAF document that F-16 pilots use to prepare for their missions.) Before departure, squadron personnel briefed the pilot on a range of subjects, including parking location, maintenance issues, aircraft configuration, notices to airmen, weather, and the mission timeline.

After departing from SSC, the F-16 proceeded to MYR, where the pilot conducted two practice instrument approaches before continuing to CHS. According to air traffic control (ATC) radar and voice communication data provided by the Federal Aviation Administration (FAA), the F-16 pilot contacted the approach controller at CHS about 1052 and requested to perform a practice tactical air navigation system (TACAN) instrument approach to runway 15. The controller instructed the F-16 pilot to fly a heading of 260° to intercept the final approach course. About 1055, the controller instructed the F-16 pilot to descend from 6,000 ft to 1,600 ft. About that time, the F-16 was located about 34 nautical miles (nm) northeast of CHS.

Cessna

Recorded airport surveillance video showed that the Cessna, which was based at MKS, departed from runway 23. At 1057:41, a radar target displaying a visual flight rules (VFR) transponder code of 1200,

and later correlated to be the accident Cessna, appeared in the vicinity of the departure end of runway 23 at MKS at an indicated altitude of 200 ft. The Cessna continued its climb and began tracking generally southeast over the next 3 minutes. For the duration of the flight, the pilot of the Cessna did not contact any ATC facilities, nor was he required to do so.

The Collision

The CHS automated radar terminal system (ARTS IIE) detected a conflict between the F-16 and the Cessna at 1059:59. According to recorded radar data, the conflict alert (CA) was presented on the radar display and aurally alarmed at 1100:13, when the F-16 and the Cessna were separated laterally by 3.5 nm and vertically by 400 ft.

At 1100:16, the CHS approach controller issued a traffic advisory advising the F-16 pilot of "traffic 12 o'clock, 2 miles, opposite direction, 1,200 [ft altitude] indicated, type unknown." At 1100:24, the F-16 pilot responded that he was "looking" for the traffic. At 1100:26, the controller advised the F-16 pilot, "turn left heading 180 if you don't have that traffic in sight." At 1100:30, the pilot asked, "confirm 2 miles?" At 1100:33, the controller stated, "if you don't have that traffic in sight turn left heading 180 immediately." As the controller was stating the instruction and over the next 18 seconds, the radar-derived ground track of the F-16 began turning southerly toward the designated heading.

At 1100:49, the radar target of the F-16 was 1/2 nm northeast of the Cessna, at an altitude of 1,500 ft, and was on an approximate track of 215°. At that time, the Cessna reported an altitude of 1,400 ft and was established on an approximate ground track of 110°. At 1100:53, the controller advised the F-16 pilot, "traffic passing below you one thousand four hundred [ft]." At 1100:54, the altitude of the F-16 remained at 1,500 ft, and the last radar return was received from the Cessna. Recorded radar data indicated that the ARTS IIE continued to provide a CA to the controller until 1101:00. The next radar target for the F-16 was not received until 1101:13. At 1101:19, the F-16 pilot transmitted a distress call, and no subsequent intelligible transmissions were received.

Several witnesses observed both airplanes in the moments leading up to the collision. One witness, located adjacent to the west branch of the Cooper River, noticed the Cessna flying overhead, roughly from west to east, and then observed the F-16 flying overhead, roughly from north to south. He estimated that the two airplanes collided at an altitude of about 900 ft. He further described that both airplanes were "very low." The F-16 struck the left side of the Cessna, and debris began falling. He reported that a large black cloud of smoke appeared after the collision but did not observe any fire. He stated that neither airplane appeared to conduct any evasive maneuvers before the collision. After the collision, the F-16 then "powered up," turned right, and flew southbound along the river.

Another witness reported that he was standing in his backyard overlooking the river. He watched as the Cessna flew by from west to east. He next saw the F-16 flying toward the Cessna, coming from the Cessna's left rear position, roughly north to south. When the F-16 collided with the left side of the Cessna, debris started falling, with some landing in his yard. He stated that it looked as if the F-16 tried to "pull up" just before impact. After the impact, the F-16 turned right and flew along the river to the south and out of sight. Once the F-16 was out of sight, he heard several loud "bang" noises.

ATC radar continued to track the F-16 as it proceeded on a southerly course. After it descended to 300

ft, radar contact was lost at 1103:17 in the vicinity of the F-16 crash site. The F-16 pilot used the airplane's emergency escape system (ejection seat) to egress, incurring minor injuries as he landed on the ground under canopy. He was subsequently met by first responders. Figure 1 shows the calculated flight track for the F-16 and the Cessna.



Figure 1. Calculated flight track for the F-16 (yellow) and the Cessna (orange). (The first witness is located north of the collision point, and the second witness is located southwest of the collision point.)

Pilot Information

Certificate:	Private	Age:	30, Male
Airplane Rating(s):	Single-engine land	Seat Occupied:	Left
Other Aircraft Rating(s):	None	Restraint Used:	Unknown
Instrument Rating(s):	None	Second Pilot Present:	No
Instructor Rating(s):	None	Toxicology Performed:	Yes
Medical Certification:	Class 3 Without waivers/limitations	Last FAA Medical Exam:	February 7, 2013
Occupational Pilot:	No	Last Flight Review or Equivalent:	December 29, 2014
Flight Time:	244 hours (Total, all aircraft), 239 hours (Total, this make and model), 58 hours (Last 90 days, all aircraft), 18 hours (Last 30 days, all aircraft), 0 hours (Last 24 hours, all aircraft)		

F-16 Pilot

According to USAF personnel, the pilot of the F-16 was current and qualified in the accident airplane as a four-ship flight lead. His additional duties at the time of the accident included the position of 55th Fighter Squadron Chief of Mobility. At the time of the accident, he had accumulated 2,383 total hours of military flight experience, including 624 hours in the F-16. The pilot's total flight experience included 1,055 hours at the controls of the MQ-1B (Predator) and 456 hours at the controls of the MQ-9 (Reaper), both unmanned aerial vehicles. (The remaining hours were in USAF training aircraft and flight simulators.) His recent experience included 35 hours in the 90 days before the accident and 24 hours in the 30 days before the accident, all in the F-16. The USAF reported that the pilot was medically qualified for flight duty and was wearing contact lenses at the time of the accident.

The F-16 pilot's most recent instrument checkride was completed on August 25, 2014, and his most recent mission (tactical) checkride was completed on March 24, 2015. According to USAF records, none of the pilot's post-pilot training checkrides contained discrepancies or downgrades.

The F-16 pilot reported during a postaccident interview that he had accumulated about 50 hours of civilian flying experience and possessed an FAA-issued commercial pilot certificate obtained through 14 CFR 61.73. He had not flown civilian aircraft since he began initial USAF pilot training in July 2005.

Cessna Pilot

The pilot of the Cessna held a private pilot certificate with a rating for airplane single-engine land issued on December 29, 2014. His most recent, and only, FAA third-class medical certificate was issued on February 7, 2013, with no waivers or limitations. The pilot's personal flight logbook was recovered from the wreckage and contained detailed entries between May 2012 and July 5, 2015. As of the final entry, the pilot had accumulated 244 total flight hours, of which 239 hours were in the accident airplane make and model. He had flown 58 hours in the 90 days before the accident and 18 hours in the 30 days before the accident. Review of FAA records revealed no history of accidents, incidents, violations, or pending investigations.

The Cessna pilot's primary flight instructor indicated in a postaccident interview that the pilot was "very

careful" and "responsive." He stated that the pilot "enjoyed" talking to ATC and was aware of the benefits. During his instruction, he would contact ATC for flight-following without being prompted. A review of the pilot's logbook revealed that he communicated with SSC ATC on at least 9 occasions and CHS ATC at least 21 times.

Air Traffic Controller

The CHS approach controller was hired by the FAA in August 2006 and attended the FAA academy in Oklahoma City before working at the Oakland Air Route Traffic Control Center. She resigned from the FAA in September 2007 and was rehired in February 2008. She worked at CHS since her rehire. Before working for the FAA, she served as an air traffic controller in the USAF from 1998 to 2000.

The controller was qualified and current on all operating positions at CHS and held no other FAA certifications. Her most recent FAA second-class medical certificate was issued on May 21, 2014, with a requirement to wear glasses while providing ATC services. She was wearing glasses on the day of the accident.

On the day of the accident, the controller was working a regularly scheduled 0700 to 1500 shift. At the time of the accident, she was working the radar west position combined with the radar east position, which was the normal radar configuration at CHS. The radar assistant position, called radar handoff, was also staffed. About 1101, when the accident occurred, she had been working the radar west position for about 1 1/2 hours.

Aircraft and Owner/Operator Information

Aircraft Make:	Cessna	Registration:	N3601V
Model/Series:	150M	Aircraft Category:	Airplane
Year of Manufacture:	1975	Amateur Built:	
Airworthiness Certificate:	Utility	Serial Number:	15076559
Landing Gear Type:	Tricycle	Seats:	2
Date/Type of Last Inspection:	October 1, 2014 Annual	Certified Max Gross Wt.:	1601 lbs
Time Since Last Inspection:		Engines:	1 Reciprocating
Airframe Total Time:	3673 Hrs as of last inspection	Engine Manufacturer:	Continental
ELT:	C91A installed, activated, did not aid in locating accident	Engine Model/Series:	O-200-A
Registered Owner:	On file	Rated Power:	100 Horsepower
Operator:	On file	Operating Certificate(s) Held:	None

Cessna

The white- and red-colored Cessna 150M was a single-engine, high-wing airplane with a conventional

tail. It was equipped with a rotating beacon light, anticollision strobe lights, navigation position lights, and a landing light. The operational status of each lighting system at the time of the accident could not be determined. Review of the airplane's maintenance and airworthiness records revealed no evidence that any supplemental equipment, such as high intensity anticollision lights, had been installed after delivery to enhance its visual conspicuity. The airplane was not equipped with a traffic advisory system (TAS), traffic alert and collision avoidance system (TCAS), or automatic dependent surveillance-broadcast (ADS-B) equipment or displays.

The Cessna was equipped with a King KX 155 single VHF communication radio, a King KT 78 mode C transponder, and an Ameri-King AK-350 altitude encoder. Review of maintenance records revealed that the most recent transponder and encoder tests per the requirements of 14 CFR 91.413 were completed on September 8, 2008. On July 20, 2012, an overhauled transponder and new altitude encoder of the same makes and models were installed. The units were ground tested in accordance with the procedures outlined in their respective maintenance manuals, but the maintenance records did not note any tests in accordance with 14 CFR 91.413. The pitot/static system was most recently tested per the requirements of 14 CFR 91.411 on April 11, 2013. The Cessna's most recent annual inspection was completed on October 14, 2014. At the time of the inspection, the airframe had accumulated 3,651 total hours of operation.

Air Force F-16

The gray-colored F-16 was a single-seat, turbofan-powered fighter airplane. Its most recent 400 hour phase inspection was completed on June 4, 2014, and it had accumulated 237 flight hours since that time. After a flight on June 11, 2015, USAF maintenance personnel completed work on the airplane's flight control system and subsequently cleared the airplane to return to service on July 2, 2015. At the time of the accident, the airframe had accumulated 4,435 total hours of operation. The airplane was not equipped with a TAS, TCAS, or ADS-B equipment or displays.

The USAF provided general information about the limitations of the F-16 radar and "identification friend or foe" (IFF) systems (more specific information is sensitive). The F-16 was equipped with a radar unit installed in the nose of the airplane that the pilot could use to locate and "lock on" to other aircraft. The radar was forward looking and limited to a search area spanning 120° directly in front of the F-16 (60° either side of center). The radar was also limited by the size of the target and was normally used to identify targets within a 40-mile range, but other settings were available. According to USAF personnel, the radar unit was designed to acquire fast moving enemy aircraft (not slow-moving, small aircraft). USAF personnel did not believe the radar would locate a small general aviation aircraft at takeoff or climb speed. The radar acquired targets by direct energy return off the target aircraft's surface and used aircraft closure rate rather than the airspeed of the other aircraft to filter out slow-moving targets.

When operating in search target acquisition mode, traffic was displayed as a small, white square target on the radar's multifunction displays (MFD), which were located on the cockpit instrument panel, near the pilot's knees. If a target existed, a subsequent sweep of the radar would reveal a new target, and the previous image would be lighter in intensity. There were no aural alerts if a new target appeared. The pilot could place a cursor over the target and "lock" the target on the radar if he/she chose. After locking on, the pilot could obtain the mean sea level (msl) altitude of the target.

The F-16 was also equipped with an IFF interrogator. Targets identified by this system would be displayed on the MFD, but it was not an integral part of the radar. The IFF interrogator could be programmed to request specific types of responses (1 to 4); most civilian aircraft with an operating ATC transponder would provide a "type 3" response. To receive any type of response, the F-16 pilot would have to manually initiate the interrogation process, which takes about 8 to 10 seconds to sweep and display all four types of responses, each being displayed for about 2 seconds.

The F-16 was equipped with a basic autopilot providing attitude hold, heading select, and steering select in the roll axis, and attitude hold and altitude hold in the pitch axis. There was no capability for autopilot-coupled instrument approaches. There were three bank settings: go-to heading, selected steer point, and hold bank angle. While the autopilot was engaged in heading select mode and a new heading was selected, the airplane would turn at about a bank angle not to exceed 30°. According to the F-16 flight manual, the autopilot was able to maintain altitude within ±100 ft under normal cruise conditions. Manual inputs through the control stick would override autopilot functions. If specific limits were exceeded during manual override, the autopilot would disconnect.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	Condition of Light:	Day
Observation Facility, Elevation:	KMKS, 73 ft msl	Distance from Accident Site:	2 Nautical Miles
Observation Time:	10:55 Local	Direction from Accident Site:	302°
Lowest Cloud Condition:	Scattered / 2600 ft AGL	Visibility	10 miles
Lowest Ceiling:	None	Visibility (RVR):	
Wind Speed/Gusts:	/	Turbulence Type Forecast/Actual:	/
Wind Direction:		Turbulence Severity Forecast/Actual:	/
Altimeter Setting:	30.14 inches Hg	Temperature/Dew Point:	30°C / 22°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	Moncks Corner, SC (MKS)	Type of Flight Plan Filed:	None
Destination:	N. Myrtle Beach, SC (CRE)	Type of Clearance:	None
Departure Time:	10:57 Local	Type of Airspace:	Class E

The area forecast that included eastern South Carolina was issued at 0445 and forecasted scattered clouds between 3,000 and 4,000 ft msl, with scattered cirrus clouds and widely scattered light rain showers and thunderstorms after 1100.

The closest facility disseminating a terminal aerodrome forecast was CHS. The last forecast published before the accident was issued at 0723. The forecast weather conditions beginning at 0800 and continuing through 1300 included variable winds at 4 knots, greater than 6 statute miles visibility, and few clouds at 4,000 ft above ground level (agl).

Review of weather radar imagery showed no precipitation in the vicinity of the accident site about the time of the accident.

The weather conditions reported at MKS at 1055 included calm wind, 10 statute miles visibility, scattered clouds at 2,600 ft agl, a temperature of 30° C, a dew point of 22° C, and an altimeter setting of 30.15 inches of mercury.

The weather conditions reported at CHS at 1055 included wind from 220° true at 7 knots, 10 statute miles visibility, scattered clouds at 4,000 ft agl, a temperature of 30° C, a dew point of 22° C, and an altimeter setting of 30.15 inches of mercury.

At the time of the accident, the sun was about 57° above the horizon at an azimuth of about 99°.

Airport Information

Airport:	BERKELEY COUNTY MKS	Runway Surface Type:	
Airport Elevation:	73 ft msl	Runway Surface Condition:	
Runway Used:		IFR Approach:	None
Runway Length/Width:		VFR Approach/Landing:	None

CHS has two intersecting runways oriented in a 15/33 and 03/21 configuration, at an elevation of 46 ft. The airport is served by numerous instrument approaches, including a VOR [very high omnidirectional range]/DME [distance measuring equipment] or TACAN approach to runway 15. The minimum altitude for the intermediate portion of the approach was 1,600 ft msl, while the minimum crossing altitude at the final approach fix, located 2.8 nm from the runway 15 threshold, was 1,100 ft msl.

ATC services at the airport are provided continuously by a combined ATC tower and terminal radar approach control (TRACON) facility. The CHS TRACON airspace extends for an approximate 40-nm radius from CHS, from the surface to 10,000 ft msl. Radar data are displayed to air traffic controllers at CHS via the ARTS IIE, with the radar feed from the airport surveillance radar (ASR-9), located at CHS.

The airport is surrounded by class C airspace, defined as that airspace extending from the surface up to and including 4,000 ft msl, within a 5-nm radius of CHS and that airspace extending from 1,200 ft msl up to and including 4,000 ft msl, within a 10-mile radius of CHS. There is no specific pilot certification required to operate within the class C airspace, but, according to 14 CFR 91.215, aircraft are required to be equipped with a two-way radio with an operable radar beacon transponder with automatic altitude reporting equipment. According to 14 CFR 91.130, before entering the class C airspace, two-way radio communication must be established and subsequently maintained with the ATC facility providing services.

Pilots requesting ATC services at CHS are required to contact the ATC facility on the publicized radio frequency and provide their position, altitude, radar beacon code, destination, and the nature of their request. Radio contact should be initiated far enough from the class C airspace boundary to preclude entering class C airspace before two-way radio communications are established. Beyond the class C airspace is an outer area that extends to a 20-nm radius of the airport. There were no specific communications or transponder requirements to operate in this area; however, approach control services could still be provided by ATC when operating in the outer area.

MKS, the Cessna's departure airport, is located about 17 nm north of CHS and is outside the CHS class C airspace. The airspace surrounding MKS and encompassing the collision location is designated as class E and extends from 700 ft agl to 17,999 ft msl. There are no two-way radio communication or transponder use requirements for operation in class E airspace. The established minimum vectoring altitude for ATC in this area is 1,600 ft, which represented the lowest altitude available to controllers when providing radar vectors to aircraft operating under IFR. Figure 2 shows an FAA sectional chart depicting CHS and class C airspace, MKS, and the approximate collision location.



Figure 2. FAA sectional aeronautical chart view depicting CHS and class C airspace, MKS, and the approximate collision location. (Not for navigational use.)

An instrument military training route (MTR), IR-18, transits generally south to north with an altitude structure of 5,000 to 7,000 ft msl, and is located about 1 nm east of MKS. A visual MTR, VR-1040/1041, transits generally east to west with an altitude structure of 200 to 1,500 ft agl and is located

about 5 nm northwest of MKS. (The F-16 was not operating on either of these MTRs.) Several military operations areas, two USAF airbases, and a National Guard airbase are located within 60 nm of MKS. The airport/facility directory entry for MKS did not provide any warning or cautions regarding low altitude, high speed military air traffic in the vicinity of the airport.

Wreckage and Impact Information

Crew Injuries:	1 Fatal	Aircraft Damage:	Destroyed
Passenger Injuries:	1 Fatal	Aircraft Fire:	None
Ground Injuries:		Aircraft Explosion:	None
Total Injuries:	2 Fatal	Latitude, Longitude:	33.160831,-79.991111

Cessna

The wreckage of the Cessna was recovered in the vicinity of its last observed radar target, over the west branch of the Cooper River. Components from both airplanes were spread over an area to the north and west of that point, extending for about 1,200 ft. The largest portions of the Cessna's airframe included a relatively intact portion of the fuselage aft of the main landing gear and the separate left and right wings, all of which were within 500 ft northwest of the airplane's final radar-observed position. Portions of the cabin interior, instrument panel, fuel system, and engine firewall were found distributed throughout the site. The engine, propeller, and nose landing gear assembly were not recovered. The lower aft engine cowling of the F-16 was also recovered in the immediate vicinity of the Cessna's aft fuselage, while the F-16's engine augments was recovered about 1,500 ft southwest. Small pieces of the F-16's airframe were also distributed throughout the accident site.

Both of the Cessna's wings displayed uniform leading-edge crush damage throughout their spans that was oriented aft and upward. Paint transfer and rub markings (consistent with paint from the F-16) oriented from left to right were observed along the upper forward surfaces of both wings. Both fuel tanks were ruptured, and evidence of heat damage and thermal paint blistering were observed on the upper surface of the right wing. Flight control continuity was traced through overload-type cable separations from the cabin area to each flight control surface. Measurement of the pitch trim actuator showed a position consistent with a 3°-to-4° deflection of the tab in the nose down direction, and measurement of the flap actuator showed a position consistent with the flaps having been in the retracted position.

Air Force F-16

The F-16 wreckage site was located about 6 nm south of the Cessna wreckage site. The F-16 wreckage path was about 700 ft long and oriented roughly 215°, with portions of the airframe distributed along the wreckage path. The wreckage displayed significant ground impact and postimpact fire-related damage.

Flight recorders

A crash-survivable memory unit (CSMU) was recovered from the wreckage of the F-16, and the digital flight control system seat data recorder was recovered from the airplane's ejection seat. Both memory units were forwarded to the airframe manufacturer for data extraction under the supervision of a National Transportation Safety Board (NTSB) vehicle recorder specialist. The data were downloaded normally with no anomalies noted.

Medical and Pathological Information

The Department of Pathology and Lab Medicine, Medical University of South Carolina, determined that the cause of death for both occupants of the Cessna was "blunt trauma." The FAA's Civil Aerospace Medical Institute performed postaccident toxicological testing on tissue specimens from the Cessna pilot. The specimens tested negative for a wide range of drugs, including major drugs of abuse. Although the specimens tested positive for ethanol, the levels of ethanol were consistent with postmortem ethanol production.

A Department of Defense Armed Forces medical examiner scientist performed postaccident toxicological testing on blood and urine specimens from the F-16 pilot, and the specimens tested negative for carbon monoxide, ethanol, and major drugs of abuse.

Tests and Research

Aircraft Performance and Cockpit Visibility Study

The NTSB's investigation examined the ability of the Cessna and F-16 pilots to see and avoid the other aircraft. To determine approximately how each aircraft would appear in the pilots' fields of view, the position of the "target" aircraft in a reference frame attached to the "viewing" aircraft must be calculated. This calculation depends on the positions and orientation (pitch, roll, and yaw angles) of each aircraft, as well as the location of the pilots' eyes relative to the cockpit windows. Data for the F-16 were derived from its CSMU, while orientation information for the Cessna was estimated based on an analysis of the radar data.

After the position and orientation of each airplane were determined, the position of each airplane in the body axis system of the other was calculated. These relative positions then determined where the "target" airplanes likely would have appeared in the fields of vision of the pilots of the "viewing" airplanes. The study assumed a nominal pilot seating (and eye) position in each cockpit and evaluated a matrix of eye displacements from the nominal eye position. For this study, the relative positions of the

two airplanes were calculated beginning when the Cessna became visible on radar and then at 1-second intervals up to the collision. The time, location, and altitude of the collision were determined based on extrapolation of the radar and F-16 CSMU data and on the location of the main Cessna wreckage. The locations of the structures and transparencies of the F-16 and Cessna in the pilots' fields of view were determined from the interior and exterior dimensions of representative airplanes, as measured using a laser scanner. The structural obscurations to each pilot's view were merged with the calculated relative position data and are discussed below. The variations in eye position changed the timing of the obscurations of the opposite aircraft by less than +/-1.5 seconds at any given point.

At 1100:16, when the controller provided the initial traffic advisory to the F-16 pilot, the F-16 was in a wings-level attitude, at an altitude of about 1,570 ft, on a ground track of 252°, and at a ground speed of 253 knots. The Cessna's calculated position was 3.25 nm from the F-16, at a position directly ahead (about 12 o'clock), and at an altitude of roughly 1,200 ft. The Cessna's ground track was 109°, and it was climbing at a rate of about 240 ft per minute. The aircraft performance and cockpit visibility study showed that, at 1100:18, the Cessna would have appeared to the F-16 pilot as a very small, stationary object just above the horizon and near the center of the airplane's heads up display (HUD) (see figure 3a); the F-16 would have appeared to the Cessna pilot as a small, stationary object just above the horizon, but outside of the left cockpit door window, near the forward vertical post of the door frame (see figure 3b).



Figure 3a. Simulated cockpit visibility from the F-16 at 1100:18, when the airplanes were 3.1 nm apart.

(Transparent shadow masks depict areas where visibility is obscured by airplane structure.)

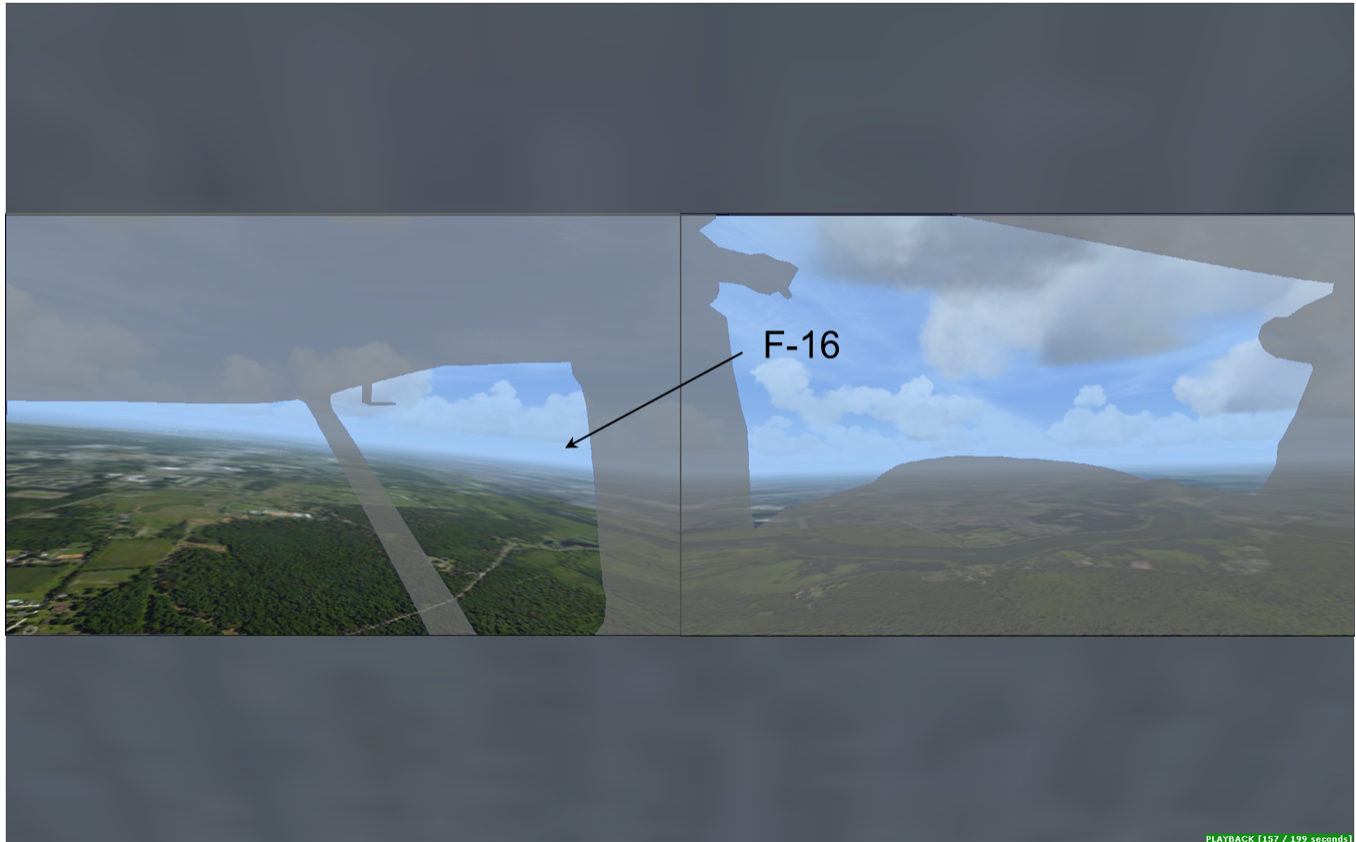


Figure 3b. Simulated cockpit visibility from the Cessna at 1100:18, when the airplanes were 3.1 nm apart. (Transparent shadow masks depict areas where visibility is obscured by airplane structure.)

At 1100:26, when the controller advised the F-16 pilot, "turn left heading 180 if you don't have that traffic in sight," the relative positions changed slightly, with the Cessna moving slightly to the left but still remaining within the F-16's HUD, and the F-16 moving slightly aft in the Cessna pilot's left window.

At 1100:33, when the controller stated, "If you don't have that traffic in sight turn left heading 180 immediately" and as the F-16 began banking to the left, the F-16 pilot's view of the Cessna would have been obscured behind the left structural frame of the HUD. The position of the F-16 would have remained unchanged to the Cessna pilot.

At 1100:49, as the F-16 was executing its left turn at a bank angle of 30°, the Cessna would have become more discernable in the lower right portion of the F 16 pilot's HUD (see figure 4a). The F-16 would also have become more discernable, visible through the Cessna pilot's left window at a point just

forward of the wing strut attachment point (see figure 4b).



Figure 4a. Simulated cockpit visibility from the F-16 at 1100:49, when the airplanes were 0.6 nm apart.



Figure 4b. Simulated cockpit visibility from the Cessna at 1100:49, when the airplanes were 0.6 nm apart.

At 1100:53, when the controller advised the F-16 pilot, "traffic passing below you" at 1,400 ft, the F-16 was flying at an altitude of 1,480 ft, while the estimated altitude of the Cessna was 1,440 ft. The closure rate of both airplanes at this point was 264 knots. The Cessna would have been visible to the right of the structural frame of the F 16's HUD, while the F-16 would have appeared to the Cessna pilot in largely the same position but with a more defined shape.

Over the next 3 seconds, the airplanes continued to approach each other, with the F-16 approaching the Cessna from its left and slightly above. The Cessna would have been completely obscured by the lower right cockpit structure of the F-16, as the airplane banked in its turn to the left (see figure 5a). The F 16 would have become partially obscured by the left wing strut (see figure 5b).



Figure 5a. Simulated cockpit visibility from the F-16 at 1100:56, when the airplanes were 260 ft apart.

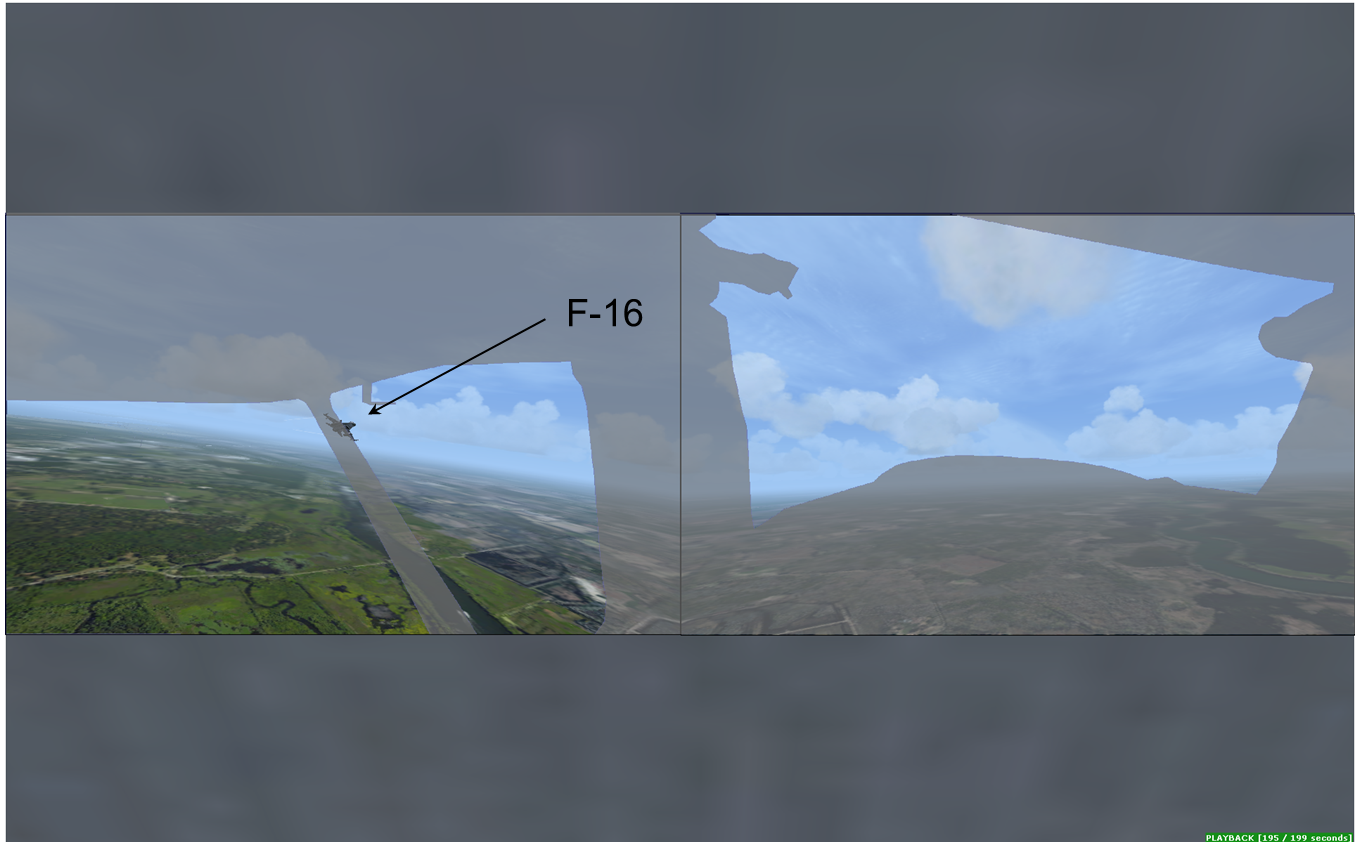


Figure 5b. Simulated cockpit visibility from the Cessna at 1100:56, when the airplanes were 260 ft apart.

In-Cockpit Traffic Display Simulation

The FAA's Aeronautical Information Manual (AIM) (dated December 10, 2015, and revised on May 26, 2016), paragraph 4-5-7, states that ADS B is a surveillance technology deployed throughout the National Airspace System. The ADS-B system is composed of aircraft avionics and a ground infrastructure. Onboard avionics determine the position of an aircraft by using the GPS and transmitting its position along with additional information about the aircraft to ground stations for use by ATC and other ADS-B services. This information is transmitted at a rate of approximately once per second. ADS-B avionics can have the ability to both transmit and receive information. The transmission of ADS-B information from an aircraft is known as ADS B Out. The receipt of ADS-B information by an aircraft is known as ADS-B In. On January 1, 2020, all aircraft operating within the airspace defined in 14 CFR 91.225 will be required to transmit the information defined in 14 CFR 91.227 using ADS-B Out avionics.

The ADS-B capabilities that enhance a pilot's awareness of airborne traffic in their vicinity are described in FAA Advisory Circular (AC) 20-172B, "Airworthiness Approval for ADS-B In Systems and Applications." Per the AC, this capability allows an appropriately equipped aircraft to receive and display another aircraft's ADS-B Out information, as well as ground station broadcast information, from services like traffic information services-broadcast (TIS-B) and automatic dependent surveillance-rebroadcast (ADS-R). The received information is processed by onboard avionics and presented to the flight crew on a display. ADS-B In avionics enable a number of aircraft surveillance applications and

can enhance visual acquisition by displaying nearby traffic on a plan view (bird's eye view) relative to own-ship. The traffic information assists pilots in visually acquiring traffic out the window while airborne but does not relieve them of see-and-avoid responsibilities. Additionally, the information derived through ADS-B In applications can be used to provide voice annunciations to flight crews to draw attention to alerted traffic.

The images from the NTSB's in-cockpit traffic display simulation presented in figures 6 and 7 are representative of the minimum operations specifications for such displays contained in RTCA document DO-317B but do not duplicate the implementation or presentation of any particular operational display exactly. The actual images presented to a pilot depend on the range scale and background graphics selected by the pilot (which could reflect various implementations and combinations of moving maps, terrain elevation data, and weather information, rather than the simple black background presented here).

For this accident, simulated in-cockpit displays of traffic information for both the F-16 and Cessna were created based on the TIS-B information that would have been displayed to the pilot of each airplane assuming that both aircraft were equipped with ADS-B In capability and avionics capable of displaying and aurally annunciating the traffic information. In addition, the simulation assumes that at least one ADS-B Out equipped aircraft was operating in the vicinity of the two accident aircraft in order to trigger the broadcast of TIS-B information from a ground station, as currently, aircraft equipped with only ADS-B In cannot trigger the broadcast of this information.

The NTSB's in-cockpit traffic display simulation for the F-16 indicates that at 1058:06, an open (outlined), cyan-colored, arrowhead-shaped target representing the Cessna would have appeared at the F-16's 12 o'clock position (straight ahead), 15 nm from and 1,300 ft below the F-16. The Cessna would have been the only target within that range from that time up to the time of the collision at 1100:57. As the airplanes approached each other, the Cessna target would have been shown turning left from west to east and then approaching the F-16 from its 12 o'clock position, slightly to the right of the F-16's flightpath, and climbing. The heading depicted by the Cessna symbol as the aircraft converged would have indicated that the Cessna's projected flightpath would cross the F-16's flightpath from right to left. At 1059:47, the Cessna symbol would have changed from an open cyan arrowhead to a filled cyan arrowhead, as the Cessna closed within 6 nm horizontally and 600 ft vertically of the F-16.

At 1100:35, as the F-16 banked into its left turn toward the south, the pilot would have received an aural alert associated with the Cessna, which by then had closed within 2 nm horizontally and 300 ft vertically. The aural alert would have advised, "Traffic, 12 o'clock, low, 2 miles." As shown in figure 6, the Cessna symbol would have changed to a filled yellow arrowhead, enclosed by a yellow circle. As the F-16 continued in its left turn, the Cessna target would have rotated to the right side of the F-16's projected course, with its heading still projected to intercept that course. At 1100:56, one second before the collision, the F-16 would have received a second aural alert of "Traffic, 2 o'clock, same altitude, zero miles." The symbol representing the Cessna would have depicted it 100 ft below the F-16 (see figure 6).

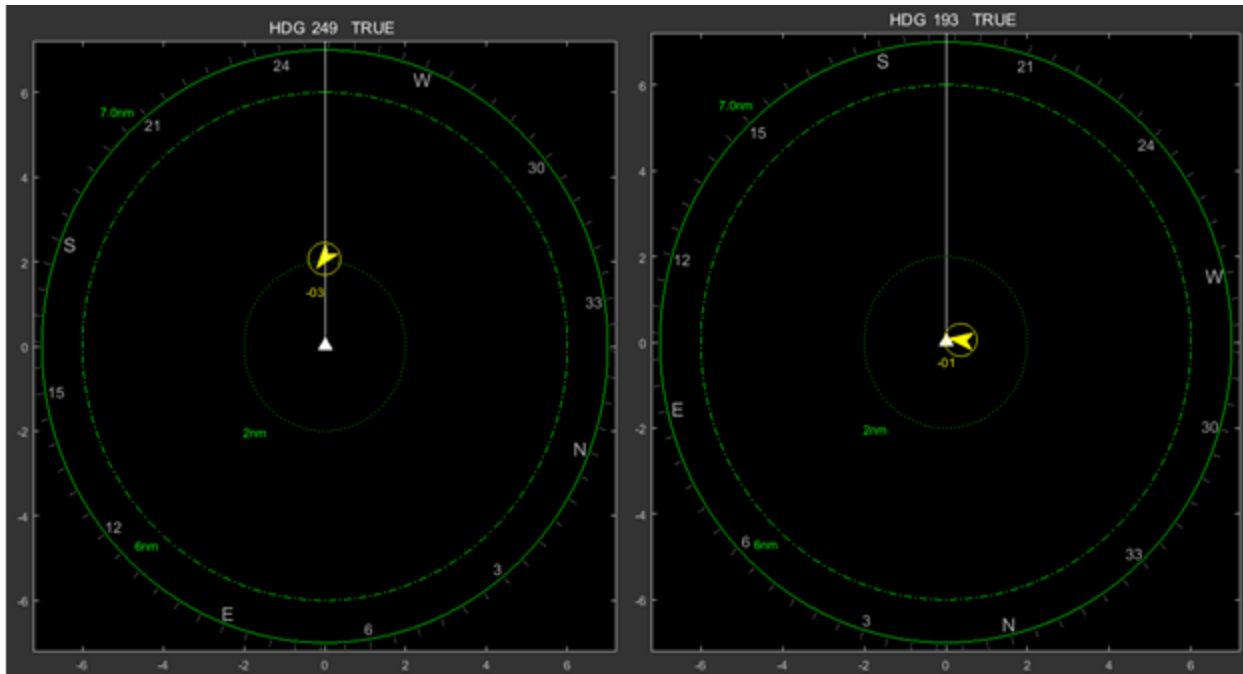


Figure 6. Simulated in-cockpit traffic display for the F-16 at 1100:35 (left) and 1100:56 (right)

The in-cockpit traffic display simulation for the Cessna indicates that at 1058:05, an open cyan target representing the F-16 would have appeared at the Cessna's 8 o'clock position, 15 nm from and 1,300 ft above the Cessna. The F-16 would have been one of two targets within that range from that time up to the time of the collision at 1100:57. The other target would have appeared between the Cessna's 12 and 1 o'clock position, about 11 nm from and 1,300 ft above the Cessna. As the Cessna turned left toward the east, the F-16 target would have rotated to the Cessna's 11 o'clock position and been depicted flying toward the Cessna. The other aircraft would have rotated to the Cessna's 3 o'clock position and been depicted flying away from the Cessna. At 1059:47, the F-16 symbol would have changed from an open cyan arrowhead to a filled cyan arrowhead, as the F-16 closed within 6 nm horizontally and 600 ft vertically of the Cessna.

At 1100:35, as the F-16 banked into its left turn toward the south, the Cessna pilot would have received an aural alert associated with the F-16, which by then had closed within 2 nm horizontally and 300 ft vertically. The aural alert would have advised, "Traffic, 11 o'clock, high, 1 mile." As shown in figure 7, the F-16 symbol would have changed to a filled yellow arrowhead, enclosed by a yellow circle. The Cessna would not have received a second aural alert for the F-16, but the F-16 symbol would have remained in alert status (filled yellow arrowhead enclosed by a yellow circle) until the collision.

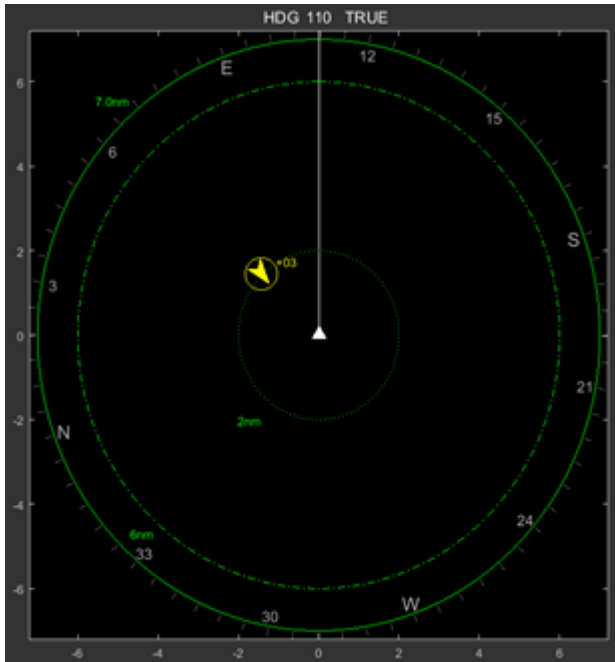


Figure 7. Simulated in-cockpit traffic display for the Cessna at 1100:35.

Organizational and Management Information

USAF Mid-Air Collision Avoidance Program

The USAF has a Mid-Air Collision Avoidance (MACA) program detailed in Air Force Instruction (AFI) 91-202, dated June 24, 2015. According to AFI 91-202, USAF flying units must have a written MACA program, and the unit safety office is responsible for its creation, documentation, and upkeep. The 20th Fighter Wing (FW) Safety Office administered the Shaw Air Force Base MACA program. The required elements are a MACA pamphlet and a poster, primarily designed for use in the civilian community. The program includes civilian outreach and incorporates interaction with pilot advocacy organizations, the FAA, local airports, and fixed base operators. The 20th FW Safety Office also maintains a public website populated with the MACA program products and other safety information. According to 20th FW Safety Office personnel, activities related to MACA are coordinated with two other military bases: Charleston Joint Base and McEntire Joint National Guard Base. The Charleston Joint Base Flight Safety office held MACA seminars at MKS in June 2012, January 2014, and March 2015.

Additional Information

Postaccident Interviews

F-16 Pilot

Members of the USAF Accident Investigation Board interviewed the F-16 pilot after the accident. He reported that he had the radar configured for a 20- and 40-mile range, manually alternating back and forth, and could not recall if his IFF interrogator was set up to receive civilian transponder replies. He was using a scan pattern that included looking outside; checking instruments for altitude, airspeed, and heading; and checking the radar display.

The F-16 pilot indicated that he had acquired and locked on a radar target 20 miles away. He stated that shortly thereafter, the controller issued an alert for traffic at his 12 o'clock position, 2 miles away, at 1,200 ft. He remarked that a 2-mile call was the "...closest call I've ever received" and that it was "...a big alert for me." He then asked the controller to "confirm two miles"; he indicated in a postaccident interview that he asked that question because he was looking at traffic on his radar at 20 miles away. He then began aggressively looking to visually acquire the airplane and recalled a command from the controller to turn left "immediately" to a heading of 180°. He stated that he used the autopilot to execute the turn so that he could continue to search outside for the traffic. The autopilot turn used 30° of bank and standard rate, or 3° per second of turn. He continued to search for the traffic until he observed the Cessna directly in front of his airplane, "within 500 feet." He then applied full aft control stick inputs to avoid a collision, but it was "too late." He estimated that the time from initial sighting of the Cessna to the impact was less than 1 second. After the collision, he attempted to maintain control of his airplane; however, once he determined that continued controlled flight was not possible, he initiated his emergency egress.

Air Traffic Controller

The air traffic controller described the traffic on the day of the accident as light and routine, with nothing out of the ordinary. Several USAF fighter aircraft from SSC were making approaches to CHS when the F-16 entered the airspace from the northeast and requested a TACAN approach. The controller told the pilot to expect the requested approach and provided climb-out instructions after completing the approach. She issued a radar vector of 260° to intercept the 10- to 15-mile final approach course for the instrument approach. The intent of this vector was to keep the F-16 south of, and to avoid overflying, MKS. The controller stated that she then directed the F-16 to descend and maintain 1,600 ft and was "pretty much done with him" while she worked other traffic, including a flight of two other F 16s. She had descended the accident airplane to 1,600 ft because that was the minimum vectoring altitude at CHS. She stated that this was her usual technique; getting aircraft to their final altitude quickly allowed her more efficient use of her time.

When the controller initially noticed the Cessna depart from MKS, she thought that it would remain in the local VFR traffic pattern. She described that, generally, pattern traffic at MKS was rare and, when present, typically stayed below 1,000 ft. She then descended the other two aircraft flight of F-16s to sequence them behind the accident F-16 and to get them around other traffic. Shortly after, she asked the two-aircraft flight to expedite its descent to 3,000 ft and noticed that the Cessna was climbing above 1,000 ft. She responded by advising the F-16 pilot, hoping that he would be able to visually acquire the traffic, but the F-16 pilot did not report the traffic in sight. She advised the F-16 pilot to turn left heading 180 if he did not have the traffic in sight.

As the radar targets were continuing to close on one another, she directed the F-16 pilot that if he did not have the traffic in sight to turn left heading 180 immediately. She reported that the 180 heading assignment was preferred over a turn to the north because the turn was quicker, and she believed that "fighters could turn on a dime." She stated that her expectation was that the word "immediately" meant to react now and that, with a fighter aircraft, it meant to do a "max performance turn" to the heading. She stated that she did not recall seeing or hearing a CA generated by the ATC radar system. The controller indicated in a postaccident interview that she chose not to direct the F 16 to climb because the altitude indicated for the Cessna's radar target was unconfirmed.

The controller advised the F-16 pilot that the Cessna had passed below him and thought the two aircraft were clear of each other until she saw the Cessna's radar target disappear followed by the F 16 pilot's distress call. She briefly initiated a call to the pilot and then turned to the radar handoff controller and told him "I don't know what to do." The radar handoff controller advised her to "separate what you've got."

ATC Radar Equipment

The radar display system in use at CHS at the time of this accident, ARTS IIE, is designed to support one or two sensors and up to 22 displays in two different configurations and can process 256 simultaneous tracks per sensor. At the time of the accident, there were no known or reported equipment discrepancies with the ARTS IIE system that would have affected the controller's ability to provide ATC services.

The ARTS IIE has numerous capabilities and functions to help controllers with strategic and tactical decision-making. One of these functions is the CA/mode C intruder, which provides controllers with visual and immutable aural warnings for aircraft that are or will be in dangerous proximity to one another. A CA provides a visual presentation on the radar scope display associated with the conflicting aircraft and an aural alarm when conditions warrant. These conditions are based on vertical and horizontal parameters established for the environment in which the aircraft are operating. For example, in an en route environment where aircraft are operating at higher altitudes and faster speeds, the parameters would be more sensitive when compared to an airport environment, where aircraft operate closer to each other and at lower speeds. For a predicted alert, the ARTS IIE evaluates a developing conflict for two of three consecutive radar sweeps. The average sweep of an ASR (a 360° scan) takes about 5 seconds.

The CHS ARTS IIE detected the conflict between the F-16 and the Cessna at 1059:59, and the CA was presented on the radar scope with an accompanying aural alert at 1100:13. The ARTS IIE continued to provide a CA to the controller until 1101:00. As the controller stated in her postaccident interview, she did not recall seeing or hearing the CA, but review of archived ATC audio revealed that her initial traffic advisory to the F-16 began at 1100:16, 3 seconds after the CA alerted. A postaccident test of the CA alarm at CHS revealed that it worked properly.

FAA and USAF Rules, Regulations, and Guidance to Pilots

Title 14 CFR 91.113 addresses aircraft right-of-way rules and states, in part, the following:

(b) General. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft.

The FAA's AIM, dated April 3, 2014, paragraph 5-5-8, includes pilot procedures for see-and-avoid while in flight and states, "When meteorological conditions permit, regardless of type of flight plan or whether or not under control of a radar facility, the pilot is responsible to see and avoid other traffic, terrain, or obstacles."

The AIM, paragraph 4-1-9, also describes operations to/from airports without an operating control tower and the use of a common traffic advisory frequency (CTAF) and states, in part, the following:

a. Airport Operations Without Operating Control Tower

1. There is no substitute for alertness while in the vicinity of an airport. It is essential that pilots be alert and look for other traffic and exchange traffic information when approaching or departing an airport without an operating control tower...To achieve the greatest degree of safety, it is essential that all radio-equipped aircraft transmit/receive on a common frequency identified for the purpose of airport advisories.

b. Communicating on a Common Frequency

The key to communicating at an airport without an operating control tower is selection of the correct common frequency...A CTAF is a frequency designated for the purpose of carrying out airport advisory practices while operating to or from an airport without an operating control tower.

The AIM describes the recommended communication procedures regarding departure aircraft on the CTAF and states, "Pilots of inbound traffic should monitor and communicate as appropriate on the designated CTAF from 10 miles to landing. Pilots of departing aircraft should monitor/communicate on the appropriate frequency from start-up, during taxi, and until 10 miles from the airport unless the CFRs or local procedures require otherwise."

The AIM, paragraph 5-5-10, describes the manner in which pilots could expect to receive traffic advisories from ATC and states the following:

a. Pilot.

1. Acknowledges receipt of traffic advisories.
2. Informs controller if traffic in sight.
3. Advises ATC if a vector to avoid traffic is desired.
4. Does not expect to receive radar traffic advisories on all traffic. Some aircraft may not appear on the radar display. Be aware that the controller may be occupied with higher priority duties and unable to issue traffic information for a variety of reasons.
5. Advises controller if service is not desired.

b. Controller.

1. Issues radar traffic to the maximum extent consistent with higher priority duties except in Class A

airspace.

2. Provides vectors to assist aircraft to avoid observed traffic when requested by the pilot.
3. Issues traffic information to aircraft in the Class B, Class C, and Class D surface areas for sequencing purposes.
4. Controllers are required to issue to each aircraft operating on intersecting or nonintersecting converging runways where projected flight paths will cross.

The Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-24A), section 13, addresses scanning procedures for visually acquiring traffic:

The pilot can contribute to collision avoidance by being alert and scanning for other aircraft. This is particularly important in the vicinity of an airport.

Effective scanning is accomplished with a series of short, regularly spaced eye movements that bring successive areas of the sky into the central visual field. Each movement should not exceed 10°, and each should be observed for at least 1 second to enable detection. Although back and forth eye movements seem preferred by most pilots, each pilot should develop a scanning pattern that is most comfortable and then adhere to it to assure optimum scanning. Even if entitled to the right-of-way, a pilot should yield if another aircraft seems too close.

(The most recent version of this handbook, FAA-H-8083-25B, was published in 2016.)

The AIM Pilot-Controller Glossary defines "immediately" as a term used by ATC or pilots when such action compliance was required to avoid an "imminent situation."

The AIM, paragraph 4-4-10, states, in part, the following about adherence to clearance:

- a. When air traffic clearance has been obtained under either visual or instrument flight rules, the pilot-in-command of the aircraft must not deviate from the provisions thereof unless an amended clearance is obtained. When ATC issues a clearance or instruction, pilots are expected to execute its provisions upon receipt. ATC, in certain situations, will include the word "IMMEDIATELY" in a clearance or instruction to impress urgency of an imminent situation and expeditious compliance by the pilot is expected and necessary for safety...
- b. When a heading is assigned or a turn is requested by ATC, pilots are expected to promptly initiate the turn, to complete the turn, and maintain the new heading unless issued additional instructions.

Air Force Manual 11-248, dated January 19, 2011, T-6 Primary Flying, addresses clearing procedures in section 1.16:

1.16. Clearing. Each crewmember is responsible for collision avoidance - regardless of rank, experience, or cockpit position - whether instrument flight rules (IFR) or VFR...Pilots have the responsibility to clear the aircraft in all directions, and although the use of radar monitoring, assigned areas, or ATC separation can assist in ensuring clearance, it does not relieve pilots of the responsibility. The following principles apply to clearing regardless of flight conditions:

1.16.1. Visual detection is the most important factor in clearing for other aircraft.

FAA Guidance to Air Traffic Controllers

FAA Order 7110.65, Air Traffic Control, prescribes ATC procedures and phraseology for use by personnel providing ATC services. Paragraph 2-1-2, "Duty Priority," states, in part, that controllers should "give first priority to separating aircraft and issuing safety alerts as required in this order. Good judgment must be used in prioritizing all other provisions of this order based on the requirements of the situation at hand."

Paragraph 2-1-5, "Expeditious Compliance," states, in part, that controllers should "use the word 'immediately' only when expeditious compliance is required to avoid an imminent situation."

Paragraph 2-1-6, "Safety Alerts," states, in part, the following:

Issue a safety alert to an aircraft if you are aware the aircraft is in a position/altitude that, in your judgment, places it in unsafe proximity to terrain, obstructions, or other aircraft....

Note—

1. The issuance of a safety alert is a first priority...once the controller observes and recognizes a situation of unsafe aircraft proximity to terrain, obstacles, or other aircraft. Conditions, such as workload, traffic volume, the quality/limitations of the radar system, and the available lead time to react are factors in determining whether it is reasonable for the controller to observe and recognize such situations. While a controller cannot see immediately the development of every situation where a safety alert must be issued, the controller must remain vigilant for such situations and issue a safety alert when the situation is recognized....

b. Aircraft Conflict/Mode C Intruder Alert. Immediately issue/initiate an alert to an aircraft if you are aware of another aircraft at an altitude that you believe places them in unsafe proximity. If feasible, offer the pilot an alternate course of action. When an alternate course of action is given, end the transmission with the word "immediately."

Phraseology—

Traffic Alert (call sign) (position of aircraft) *Advise*

You turn left/right (heading),

and/or

Climb/Descend (specific altitude if appropriate)

Immediately.

Paragraph 2-1-21, "Traffic Advisories," states the following:

Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may diminish to less than the applicable separation minima. Where no separation minima applies, such as for

VFR aircraft outside of Class B/Class C airspace, or a TRSA [terminal radar service area], issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it. Provide this service as follows:

a. To radar identified aircraft:

1. Azimuth from aircraft in terms of the 12-hour clock, or
2. When rapidly maneuvering aircraft prevent accurate issuance of traffic as in 1 above, specify the direction from an aircraft's position in terms of the eight cardinal compass points (N, NE, E, SE, S, SW, W, and NW). This method must be terminated at the pilot's request.
3. Distance from aircraft in miles.
4. Direction in which traffic is proceeding and/or relative movement of traffic.

Note—

Relative movement includes closing, converging, parallel same direction, opposite direction, diverging, overtaking, crossing left to right, crossing right to left.

5. If known, type of aircraft and altitude.

Phraseology—Traffic, (number) o'clock, or when appropriate,

(direction) (number) miles, (direction)—bound and/or (relative movement),

and if known,

(type of aircraft and altitude).

or

When appropriate,

(type of aircraft and relative position), (number of feet) feet above/below you.

If altitude is unknown,

Altitude unknown.

Example—

"Traffic, eleven o'clock, one zero miles, southbound, converging, Boeing Seven Twenty Seven, one seven thousand."

"Traffic, twelve o'clock, one five miles, opposite direction, altitude unknown."

"Traffic, ten o'clock, one two miles, southeast bound, one thousand feet below you."

6. When requested by the pilot, issue radar vectors to assist in avoiding the traffic, provided the aircraft to be vectored is within your area of jurisdiction or coordination has been effected with the sector/facility in whose area the aircraft is operating.

7. If unable to provide vector service, inform the pilot.

8. Inform the pilot of the following when traffic you have issued is not reported in sight:

(a) The traffic is no factor.

(b) The traffic is no longer depicted on radar.

*Phraseology—
Traffic no factor/no longer observed,*

or

(number) o'clock traffic no factor/no longer observed,

or

(direction) traffic no factor/no longer observed.

b. To aircraft that are not radar identified:

1. Distance and direction from fix.
2. Direction in which traffic is proceeding.
3. If known, type of aircraft and altitude.
4. ETA over the fix the aircraft is approaching, if appropriate.

*Phraseology—
Traffic, (number) miles/minutes (direction) of (airport or fix), (direction)—bound,*

and if known,

(type of aircraft and altitude),

estimated (fix) (time),

or

traffic, numerous aircraft vicinity (location).

If altitude is unknown,

Altitude unknown.

Example—

"Traffic, one zero miles east of Forsythe V-O-R, Southbound, M-D Eighty, descending to one six thousand."

"Traffic, reported one zero miles west of Downey V-O-R, northbound, Apache, altitude unknown, estimated Joliet V-O-R one three one five."

"Traffic, eight minutes west of Chicago Heights V-O-R, westbound, Mooney, eight thousand, estimated Joliet V-O-R two zero three five."

"Traffic, numerous aircraft, vicinity of Delia airport."

c. For aircraft displaying Mode C, not radar identified, issue indicated altitude.

Example—

"Traffic, one o'clock, six miles, eastbound, altitude indicates six thousand five hundred."

The See-and-Avoid Concept

The FAA issued AC 90-48C, "Pilots' Role in Collision Avoidance," in 1983 to alert all pilots "...to the potential hazards of midair collisions and near midair collision [NMAC], and to emphasize those basic problem areas related to the human causal factors where improvements in pilot education, operating practices, procedures, and improved scanning techniques are needed to reduce midair conflicts." (This version of the AC was in place at the time of the accident; an updated version, AC 90-48D, was issued in April 2016 and is discussed further below.)

AC 90-48C stated that each person operating an aircraft, regardless of whether the operation was conducted under IFR or VFR, shall maintain a vigilant lookout for other aircraft at all times. Regarding visual scanning, the AC specifically stated that "Pilots should remain constantly alert to all traffic movement within their field of vision, as well as periodically scanning the entire visual field outside of their aircraft to ensure detection of conflicting traffic" (emphasis in the original). AC 90-48C also described several specific methods that pilots could use to visually acquire other traffic.

AC 90-48C also discussed the use of ATC services:

One of the major factors contributing to the likelihood of NMAC incidents in terminal areas that have an operating air traffic control (ATC) system has been the mix of known arriving and departing aircraft with unknown traffic. The known aircraft are generally in radio contact with the controlling facility (local, approach, or departure control) and the other aircraft are neither in two-way radio contact nor identified by ATC at the time of the NMAC. (emphasis in the original)

The AC recommended that pilots use ATC traffic advisory services but stressed that those services do not lessen the pilot's obligation to see and avoid other traffic.

Finally, the AC provided data on the time required for a pilot to recognize an approaching aircraft and execute an evasive maneuver. The total time to identify an approaching aircraft, recognize a collision course, decide on action, execute the control movement, and allow the aircraft to respond was estimated to be around 12.5 seconds.

In 1991, the Australian Transport Safety Bureau (ATSB) published a research report titled *Limitations of the See-and-Avoid Principle*. The report discusses the role of the see-and-avoid concept in preventing collisions and some of its inherent limitations:

Cockpit workload and other factors reduce the time that pilots spend in traffic scans. However, even when pilots are looking out, there is no guarantee that other aircraft will be sighted. Most cockpit windscreen configurations severely limit the view available to the pilot. The available view is frequently interrupted by obstructions such as window-posts which totally obscure some parts of the view and make other areas visible to only one eye.... Visual scanning involves moving the eyes in order to bring successive areas of the visual field onto the small area of sharp vision in the centre of the eye. The process is frequently unsystematic and may leave large areas of the field of view unsearched.... The physical limitations of the human eye are such that even the most careful search does not guarantee that traffic will be sighted.... An object which is smaller than the eye's acuity threshold is unlikely to be detected and even less likely to be identified as an approaching aircraft.... The human visual system is

better at detecting moving targets than stationary targets, yet in most cases, an aircraft on a collision course appears as a stationary target in the pilot's visual field. The contrast between an aircraft and its background can be significantly reduced by atmospheric effects, even in conditions of good visibility. An approaching aircraft, in many cases, presents a very small visual angle until a short time before impact. In addition, complex backgrounds such as ground features or clouds hamper the identification of aircraft via a visual effect known as 'contour interaction'. This occurs when background contours interact with the form of the aircraft, producing a less distinct image. Even when an approaching aircraft has been sighted, there is no guarantee that evasive action will be successful.

The ATSB report also discusses the value of alerted versus unalerted searches for traffic:

A traffic search in the absence of traffic information is less likely to be successful than a search where traffic information has been provided because knowing where to look greatly increases the chance of sighting the traffic (Edwards and Harris 1972). Field trials conducted by John Andrews found that in the absence of a traffic alert, the probability of a pilot sighting a threat aircraft is generally low until a short time before impact. Traffic alerts were found to increase search effectiveness by a factor of eight. A traffic alert from ATS or from a radio listening watch is likely to be similarly effective (Andrews 1977, Andrews 1984, Andrews 1987).

The ATSB report concludes, in part, that "The see-and-avoid principle in the absence of traffic alerts is subject to serious limitations....Unalerted see-and-avoid has a limited place as a last resort means of traffic separation at low closing speeds but is not sufficiently reliable to warrant a greater role in the air traffic system."

Cockpit Display of Traffic Information

In April 2016, the FAA published an update to "Pilots' Role in Collision Avoidance" (AC 90 48D), which highlights aircraft systems and technologies available to improve safety and aid in collision avoidance. Among those technologies, the recommended safety equipment includes TAS, TCAS (I and II), and ADS-B with display capability. The updated AC also discusses the information provided by each of these systems and stresses that they are intended as a supplement to, and not replacement for, the visual acquisition and avoidance of other aircraft.

Regarding the use of ADS-B as a tool to aid in a pilot's situational awareness, the AC states, in part, the following:

ADS-B is a system for air traffic surveillance. The FAA has mandated ADS-B Out by 2020 on all aircraft operating in current Mode C airspace (around Class B and C airspace and above 10,000 feet). With ADS-B, each aircraft broadcasts its own Global Positioning System (GPS) position along with other information like heading, ground track, groundspeed, and altitude (ADS-B Out). To see other aircraft, you must be equipped with ADS-B In to process the data signals.

The AC describes how other systems that actively interrogate other aircraft would continue to be useful beyond the FAA-mandated ADS-B Out requirement in 2020:

Active Traffic Systems. Active traffic systems (including TAS and TCAS) use Mode A, C, or S

transponder interrogations to determine aircraft bearing and distance. Altitude is determined by reported Mode C altitude. After 2020, aircraft will be required to broadcast ADS-B Out and this data can be interpreted by aircraft with ADS-B In, but aircraft will still be required to have a Mode C or S transponder in airspace where it is currently required; thus, active traffic systems will continue to function. Most TAS systems will have ADS-B In capability available as an upgrade so these systems can interpret signals from either source.

Active Traffic Systems in an ADS-B Environment. Active traffic systems are valuable for three reasons in an ADS-B environment. First, even after January 1, 2020, not all aircraft will have ADS-B Out, particularly in airspace which does not require it. Thus, without an active traffic system, those unequipped aircraft would not display on a cockpit traffic display even if you had ADS-B In. Second, an active traffic system will display all aircraft independent of the type of ADS-B Out, since all aircraft will still be required to have a Mode C or Mode S transponder. Third, ADS-B is dependent on GPS signals, so during periods of poor satellite geometry or solar storms, GPS position and thus ADS-B could be disrupted and less reliable, meaning an active traffic system can act as a backup to ADS-B in the cockpit.

In 1977, the Massachusetts Institute of Technology published a report for the FAA, titled Air to Air Visual Acquisition Performance with Pilot Warning Instruments (PWI), which describes how PWI could be used to aid pilots in the visual acquisition task. These instruments would generally use some electronic means to detect and then present pilots with information about particular threats, focusing their attention to where it was most needed:

The primary intent of PWI is to improve the search performance of the pilot. The PWI alarm ensures that scanning will be given high priority when it is most critical and by directing the pilot's search to a particular sector, the area to be scanned is greatly reduced. Another effect discovered in the IPC [Intermittent Positive Control]/PWI flight tests is the tendency of PWI to reduce the effect of airframe obstruction. Not only do pilots shift their positions within the cockpit in an effort to scan a threat sector, but many pilots alter the aircraft attitude in order to achieve an unobstructed view in the threat direction. Thus, PWI favorably affects the first two elements of acquisition (search and field of view). It does not alter detectability or speed of approach in any direct way.

Research into pilots' performance in the visual acquisition task conducted in support of the report found that "Unaided visual acquisition is effective as a means of separation assurance only for lower values of crossing angles (relative heading). At higher values of crossing angle the increased closure speeds and decreased visible areas reduce performance considerably."

In our report regarding a midair collision over the Hudson River (Midair Collision Over Hudson River, Piper PA-32R-300, N71MC, and Eurocopter AS350BA, N401LH, Near Hoboken, New Jersey, August 8, 2009, AAR-10/05), the NTSB stated, in part, the following;

There are inherent limitations associated with the see-and-avoid concept as the primary method for aircraft separation. These limitations include a pilot's ability to perform systematic scans, competing operational task demands, environmental factors, and blind spots associated with an aircraft's structure. Traffic advisory systems can provide pilots with additional information to facilitate pilot efforts to maintain awareness of and visual contact with nearby aircraft to reduce the likelihood of a collision.

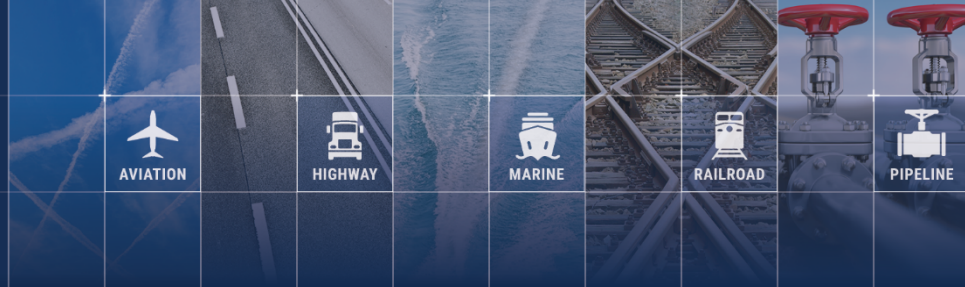
Most traffic advisory systems, including TIS [traffic information service], have visual displays of nearby traffic that show an aircraft's position or distance, direction of travel, and relative altitude and indicate whether the aircraft is climbing or descending. The NTSB recognizes that incorporating a visual traffic display into a pilot's scan could increase workload, but any increase in workload would be offset by the safety benefits resulting from the augmented awareness of other aircraft operating in the area, as displayed by the traffic system. However, these safety benefits are not a substitute for the see-and-avoid concept. In fact, Garmin guidance stated that TIS does not relieve pilots of their responsibility to see and avoid other aircraft. Thus, pilots are responsible for paying attention to the position of other aircraft for collision avoidance and not relying solely on a traffic advisory system for aircraft position information.

Administrative Information

Investigator In Charge (IIC):	Diaz, Dennis
Additional Participating Persons:	James Dangerfield; FAA/FSDO; West Columbia, SC Paul E Yoos; Textron Aviation; Wichita, KS Randolph Rushworth; USAF; Albuquerque, NM James Estes; FAA/AJI; Washington, DC Eric Stormfels; NATCA; Washington, DC Marcus Tibbs; Lockheed Martin Aeronautics; Fort Worth, TX Kenneth Worrell; Lockheed Martin Aeronautics; Fort Worth, TX Robert Koehler; Lockheed Martin Aeronautics; Fort Worth, TX David Vandercook; Lockheed Martin Aeronautics; Fort Worth, TX Dennis Lasater; Lockheed Martin Aeronautics; Fort Worth, TX Jacob Hannusch; Lockheed Martin Aeronautics; Fort Worth, TX Stephen Guest; Lockheed Martin Aeronautics; Fort Worth, TX Kyle Ringgenberg; Lockheed Martin Aeronautics; Fort Worth, TX
Original Publish Date:	November 15, 2016
Last Revision Date:	July 8, 2024
Investigation Class:	Class 2
Note:	The NTSB traveled to the scene of this accident.
Investigation Docket:	https://data.nts.gov/Docket?ProjectID=91508

The National Transportation Safety Board (NTSB) is an independent federal agency charged by Congress with investigating every civil aviation accident in the United States and significant events in other modes of transportation—railroad, transit, highway, marine, pipeline, and commercial space. We determine the probable causes of the accidents and events we investigate, and issue safety recommendations aimed at preventing future occurrences. In addition, we conduct transportation safety research studies and offer information and other assistance to family members and survivors for each accident or event we investigate. We also serve as the appellate authority for enforcement actions involving aviation and mariner certificates issued by the Federal Aviation Administration (FAA) and US Coast Guard, and we adjudicate appeals of civil penalty actions taken by the FAA.

The NTSB does not assign fault or blame for an accident or incident; rather, as specified by NTSB regulation, “accident/incident investigations are fact-finding proceedings with no formal issues and no adverse parties ... and are not conducted for the purpose of determining the rights or liabilities of any person” (Title 49 *Code of Federal Regulations* section 831.4). Assignment of fault or legal liability is not relevant to the NTSB’s statutory mission to improve transportation safety by investigating accidents and incidents and issuing safety recommendations. In addition, statutory language prohibits the admission into evidence or use of any part of an NTSB report related to an accident in a civil action for damages resulting from a matter mentioned in the report (Title 49 *United States Code* section 1154(b)). A factual report that may be admissible under 49 *United States Code* section 1154(b) is available [here](#).



Aviation Investigation Final Report

Location:	Moncks Corner, South Carolina	Accident Number:	ERA15MA259
Date & Time:	July 7, 2015, 11:00 Local	Registration:	96-0085
Aircraft:	LOCKHEED-MARTIN F-16CM	Aircraft Damage:	Destroyed
Defining Event:	Midair collision	Injuries:	1 Minor
Flight Conducted Under:	Armed Forces		

Analysis

The pilot of the F-16, who was operating on an instrument flight rules (IFR) flight plan, was in contact with air traffic control (ATC) and was provided radar vectors for a practice instrument approach to Charleston Air Force Base/International Airport (CHS), Charleston, South Carolina; the F-16 descended to an altitude of about 1,600 ft mean sea level as instructed by the air traffic controller. Shortly thereafter, the Cessna departed under visual flight rules (VFR) from a nearby nontowered airport; the Cessna pilot was not in contact with ATC, nor was he required to be, and had not requested traffic advisory (flight-following) services. As the Cessna continued its departure climb, the airplanes converged to within about 3.5 nautical miles (nm) laterally and 400 ft vertically, triggering a conflict alert (CA) on the controller's radar display and an aural alarm. About 3 seconds later, the air traffic controller issued a traffic advisory notifying the F-16 pilot of the position, distance, and indicated altitude of the radar target that corresponded to the Cessna, stating that the aircraft type was unknown. When the F-16 pilot replied that he was looking for the traffic, the controller issued a conditional instruction to the F-16 pilot to turn left if he did not see the airplane. The F-16 pilot did not see the airplane and responded, asking "confirm two miles?" The controller responded, "if you don't have that traffic in sight turn left heading 180 immediately." As the controller began this transmission, the F-16 pilot initiated a standard rate (approximately) left turn using the autopilot so that he could continue to visually search for the traffic; however, the airplanes continued to converge and eventually collided about 40 seconds after the controller's traffic advisory notifying the F-16 pilot of traffic. (Figure 1 in the factual report for this accident shows the calculated flight tracks for the Cessna and F-16.)

Air Traffic Controller and F-16 Pilot Performance

During postaccident interviews, the controller reported that when she observed the Cessna's target on her radar display as it departed, she thought that the airplane would remain within its local traffic pattern, which was not the case. Therefore, it was not until the airplanes were within about 3.5 nm and 400 vertical ft of one another that the controller notified the F-16 pilot of the presence of the traffic by issuing the traffic advisory, which was about 3 seconds after the ATC radar CA alarmed. (Federal

Aviation Administration [FAA] Order 7110.65, Air Traffic Control, paragraph 2-1-21, "Traffic Advisories," states, in part, that a controller should "Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may diminish to less than the applicable separation minima. Where no separation minima applies, such as for VFR aircraft outside of Class B/Class C airspace, or a TRSA [terminal radar service area], issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it. ...")

When the controller issued the traffic advisory, about 40 seconds before the eventual collision, the F-16 and the Cessna had a closure rate of about 300 knots. If the F-16 pilot had reported the Cessna in sight after the controller's traffic advisory, the controller likely would have directed the F-16 pilot to maintain visual separation, which is a common controller technique to separate aircraft. While the controller tried to ensure separation between the airplanes, her attempt at establishing visual separation at so close a range and with the airplanes converging at such a high rate of speed left few options if visual separation could not be obtained.

The options available to the controller when issuing instructions to the F-16 pilot to avoid the conflict included a turn, climb, some combination thereof, or not issuing an instruction at all. (An instruction to descend was not an option because the F-16 was already at the minimum vectoring altitude for the area.) The controller indicated in a postaccident interview that she chose not to instruct the F-16 to climb because the altitude indicated for the Cessna's radar target was unconfirmed (the Cessna pilot had not contacted ATC). An element informing the controller's decision-making as to which instruction to provide was likely the flow of other traffic into the airport at that time. Arriving aircraft, including the accident F-16, were being sequenced to runway 15 via the final approach course extending from the approach end of the runway. Given the traffic flow, the left turn instruction to the F-16 would have kept the airplane on a heading closer toward, rather than farther from, its destination and would have made returning the F-16 to the intended final approach course much easier. However, the controller's instruction to the F-16 pilot to turn left required the F-16's path to cross in front of the Cessna. Although this decision was not contrary to FAA guidance for air traffic controllers, it was the least conservative decision, as it was most dependent on the F-16 pilot's timely action for its success.

Further, the controller issued the instruction to turn left if the F-16 pilot did not have the Cessna in sight. The F-16 pilot responded to the controller's conditional instruction with a question ("confirm two miles?") that indicated confusion about the distance of the traffic. The F-16 pilot's attempt to visually acquire the Cessna per the controller's conditional instruction likely resulted in a slight delay in his beginning the turn. The collision likely would have been avoided had the F-16 pilot initiated the left turn, as ATC instructed, when he realized that he did not have the traffic in sight. About 7 seconds elapsed between the beginning of the controller's first conditional instruction to turn and the beginning of her subsequent conditional instruction to the F-16 pilot to turn "immediately." Analysis of the radio transmission recordings and the F-16's flight recorder data showed that, as the controller was making the subsequent conditional instruction, the F-16 pilot began turning to the left, which pointed his aircraft toward the Cessna.

Due to the closure rate, the close proximity of the two airplanes, and human cognitive limitations, the controller did not recover from her ineffective visual separation plan, which placed the airplanes in closer proximity to each other, and switch to an alternative method of separation. The controller's best

course of action would have been to instruct the F-16 pilot to turn before the airplanes came into close proximity with each other and preferably in a direction that did not cross in front of the Cessna's path.

In postaccident interviews, the controller stated that when she issued the command to the F-16 pilot to turn left "immediately," she expected that the F-16 pilot would perform a high performance maneuver and that she believed that fighter airplanes could "turn on a dime." The FAA's Aeronautical Information Manual (AIM) Pilot-Controller Glossary defines "immediately" as a term used by ATC or pilots "when such action compliance is required to avoid an imminent situation." Further, the AIM states that controllers should use the term "immediately" to "impress urgency of an imminent situation" and that "expeditious compliance by the pilot is expected and necessary for safety." As described above, the F-16 pilot did not meet her expectation that the turn be conducted at a greater-than-standard rate.

The controller's expectation of the F-16 pilot's performance was based on her assumption that a fighter airplane would perform a high performance turn to the heading; however, this expectation of performance was not clearly communicated. Based on the controller's instructions and the actions of the F-16 pilot in response, it is clear that the term "immediately" held different expectations for both parties. Although the controller's use of the term "immediately" was in keeping with FAA guidance, further clarification of her expectation, such as directing the pilot to "expedite the turn," would have removed any ambiguity.

See-and-Avoid Concept

According to 14 Code of Federal Regulations 91.113, "Right-of-Way Rules," "when weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft." The concept that pilots are primarily responsible for collision avoidance was similarly stressed in US Air Force training documents. In addition, FAA Advisory Circular (AC) 90-48C, "Pilots' Role in Collision Avoidance," which was in effect at the time of the accident, stated that the see-and-avoid concept requires vigilance at all times by each pilot, regardless of whether the flight is conducted under IFR or VFR. (AC 90-48D replaced AC 90-48C in 2016 and contains the same statement.)

The see-and-avoid concept relies on a pilot to look through the cockpit windows, identify other aircraft, decide if any aircraft are collision threats, and, if necessary, take the appropriate action to avert a collision. There are inherent limitations of this concept, including limitations of the human visual and information processing systems, pilot tasks that compete with the requirement to scan for traffic, the limited field of view from the cockpit, and environmental factors that could diminish the visibility of other aircraft.

Factors Impacting the Pilots' Ability to Detect Other Traffic

The collision occurred in a relatively low-density air traffic environment in visual meteorological conditions (VMC). The Cessna was equipped with an operating transponder and single communication radio but was not equipped with any technologies in the cockpit that display or alert of traffic conflicts, such as traffic advisory systems, traffic alert and collision avoidance systems, or automatic dependent surveillance-broadcast systems. The Cessna had departed from a nontowered airport and was still in close proximity to the airport when the collision occurred. The Cessna pilot had not requested or received flight-following services from ATC at the time of the collision, nor was he required to do so.

Based on his proximity to the departure airport, it is reasonable to expect that the Cessna pilot likely was monitoring that airport's common traffic advisory frequency (CTAF) for awareness of airplanes in the vicinity of the airport, as recommended by the FAA's AIM. Based on statements from the Cessna pilot's flight instructor and from his logbook entries, which both cited past experience communicating with ATC, it is also reasonable to assume that had the collision not occurred, the pilot likely would have contacted ATC at some point during the flight to request flight-following services.

Due to the Cessna's lack of technologies in the cockpit that display or alert of traffic conflicts and the pilot's lack of contact with ATC, his ability to detect other traffic in the area was limited to the see-and-avoid concept. While not required, had the Cessna been equipped with a second communication radio, the pilot could have used it to contact ATC while still monitoring the departure airport's CTAF. Had the Cessna pilot contacted ATC after departing and received ATC services, the controller would have had verification of the Cessna's altitude readout and its route of flight, which would have helped her decision-making process. The controller also could have provided the Cessna pilot awareness of the F-16.

The F-16 was operating under IFR in VMC. The F-16 pilot's ability to detect other traffic was limited to the see-and-avoid concept, supplemented with ATC traffic advisories. While the F-16 pilot could use the airplane's tactical radar system to enhance his awareness of air traffic, it was designed to acquire fast-moving enemy aircraft rather than slow-moving, small aircraft and was thus unable to effectively detect the Cessna. (The radar system did detect a target 20 miles away, which is likely what led the F-16 pilot to question the location of the traffic that the controller had indicated was 2 miles away.) The F-16 was not otherwise equipped with any technologies in the cockpit that display or alert of traffic conflicts. The F-16 pilot did eventually visually acquire the Cessna but only when the airplanes were within about 430 ft of one another, about 1 second before the accident.

A factor that can affect the visibility of traffic in VMC is sun glare, which can prevent a pilot from detecting another aircraft when it is close to the position of the sun in the sky. For the F-16 pilot, the sun would have been behind and to his left as the airplanes approached one another. Although the Cessna pilot would have been heading toward the sun, the sun's calculated position would likely have been above a point obstructed by the Cessna's cabin roof and would not have been visible to the Cessna pilot. Thus, sun glare was not a factor in this accident.

Aircraft Performance and Cockpit Visibility Study

Our aircraft performance and cockpit visibility study showed that, as the accident airplanes were on converging courses, they each would have appeared as small, stationary, or slow-moving objects to the pilots. Given the physiological limitations of vision, both pilots would have had difficulty detecting the other airplane. Specifically, the study showed that the Cessna would have appeared as a relatively small object through the F-16's canopy, slowly moving from the center of the transparent heads-up display (HUD) to the left of the HUD. As the F-16 started the left turn as instructed by the air traffic controller, the Cessna moved back toward the center of the HUD and then off to its right side, where it may have been obscured by the right structural post of the HUD. It was not visible again until about 2 seconds before the collision. (Figures 3a and 5a in the factual report for this accident show the simulated cockpit visibility from the F-16 at 1100:18 and 1100:56, respectively.) The F-16 pilot reported that before the controller alerted him to the presence of traffic, he was actively searching for traffic both visually and using the airplane's targeting radar. He reported that after the controller advised him of traffic, he was

looking "aggressively" to find it. By the time he was able to visually acquire the Cessna, it was too late to avert the collision.

Our investigation could not determine to what extent the Cessna pilot was actively conducting a visual scan for other aircraft. Our aircraft performance and cockpit visibility study showed that the F-16 would have remained as a relatively small and slow-moving object out the Cessna's left window (between the Cessna's 9 and 10 o'clock positions) until less than 5 seconds before the collision. Given the speed of the F-16, the Cessna pilot likely would not have had adequate time to recognize and avoid the impending collision.

Cockpit Display of Traffic Information

Although the Cessna and F-16 pilots were responsible for seeing and avoiding each other, our aircraft performance and cockpit visibility study showed that, due to the physiological limitations of vision and the relative positions of the airplanes, both pilots would have had difficulty detecting the other airplane. Research indicates that any mechanism to augment and focus pilots' visual searches can enhance their ability to visually acquire traffic. (AC 90-48D highlights aircraft systems and technologies available to improve safety and aid in collision avoidance, and our report regarding a midair collision over the Hudson River [AAR-10/05] states that "traffic advisory systems can provide pilots with additional information to facilitate pilot efforts to maintain awareness of and visual contact with nearby aircraft to reduce the likelihood of a collision. ...") One such method to focus a pilot's attention and visual scan is through the use of cockpit displays and aural alerts of potential traffic conflicts. Several technologies can provide this type of alerting by passively observing and/or actively querying traffic. While the accident airplanes were not equipped with these types of systems, their presence in one or both cockpits might have changed the outcome of the event. (The images from our in-cockpit traffic display simulation are representative of the minimum operations specifications contained in RTCA document DO-317B, Minimum Operational Performance Standards for Aircraft Surveillance Applications System [dated June 17, 2014], but do not duplicate the implementation or presentation of any particular operational display exactly; the actual images presented to a pilot depend on the range scale and background graphics selected by the pilot.)

Because the Cessna pilot was not in contact with ATC and was relying solely on the see-and-avoid concept, an indication of approaching traffic might have allowed him to visually acquire the F-16 and take action to avoid it. While most systems are limited to aiding pilots in their visual acquisition of a target and do not provide resolution advisories (specific maneuvering instructions intended to avoid the collision), the augmentation of a pilot's situational awareness might allow the pilot to change the flightpath in anticipation of a conflict and, thus, avoid airplanes coming in close proximity to one another. The Cessna pilot might have noted the presence of the F-16 and its level altitude of about 1,600 ft as he continued his departure climb. With this information, the Cessna pilot might have arrested his airplane's climb as he began a visual search, thus creating an additional vertical buffer between his airplane and the approaching F-16.

While the F-16 pilot's visual search was augmented by the controller's traffic advisory, a successful outcome would have depended upon the pilot's visual acquisition of the target airplane in time to take evasive action. Our in-cockpit traffic display simulation showed that the F-16 pilot might have first observed the Cessna when it was about 15 nm away, or nearly 3 minutes before the collision. As the F-16 closed to within 6 nm of the Cessna, or slightly more than 1 minute before the collision, the conflict

might have become even more apparent to the pilot showing that not only were the airplanes in close proximity laterally but also that they were only separated vertically by 600 ft. As the F-16 pilot was beginning his left turn as instructed by ATC, the presence of the Cessna would have been aurally annunciated, and its traffic symbol would have changed from a cyan color to a yellow color. The information presented on the in-cockpit traffic display would have clearly indicated that the airplanes were on a collision course that might not be resolved by a left turn and that the vertical separation between the airplanes had decreased to 300 ft.

Consequently, an in-cockpit traffic display could have helped the F-16 pilot recognize the potential for a collision in advance of the controller's instruction to turn left. The earlier warning also could have provided him additional time to conduct his visual search for the Cessna and potentially take other preemptive action to avoid the collision. Had the F-16 been equipped with a system that was able to provide the pilot with resolution advisories, the F-16 pilot could have taken action in response to that alarm to avoid the collision, even without acquiring the Cessna visually.

Postaccident Actions

In November 2016, we issued safety recommendations to the FAA and Midwest Air Traffic Control, Robinson Aviation, and Serco (companies that operate federal contract towers) to (1) brief all air traffic controllers and their supervisors on the ATC errors in this midair collision and one that occurred on August 16, 2015, near San Diego, California; and (2) include these midair collisions as examples in instructor-led initial and recurrent training for air traffic controllers on controller judgment, vigilance, and/or safety awareness.

In November 2016, we also issued a safety alert titled "Prevent Midair Collisions: Don't Depend on Vision Alone" to inform pilots of the benefits of using technologies that provide traffic displays or alerts in the cockpit to help separate safely. (In May 2015 [revised in December 2015], we issued a safety alert titled "See and Be Seen: Your Life Depends on It" regarding the importance of maintaining adequate visual lookout.)

After the accident, the Cessna's departure airport engaged in several outreach efforts (including posting midair collision avoidance materials locally and having outreach meetings with pilots) to raise awareness regarding midair collisions and encourage contact with ATC. The airport also updated its chart supplement to note the presence of military and other traffic arriving at and departing from CHS.

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be: The approach controller's failure to provide an appropriate resolution to the conflict between the F-16 and the Cessna. Contributing to the accident were the inherent limitations of the see-and-avoid concept, resulting in both pilots' inability to take evasive action in time to avert the collision.

Findings

Personnel issues	Decision making/judgment - ATC personnel
Personnel issues	Visual function - Pilot
Personnel issues	Visual function - Pilot of other aircraft

Factual Information

History of Flight

Approach	Midair collision
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On July 7, 2015, about 1101 eastern daylight time, a Cessna 150M, N3601V, and a Lockheed Martin F-16CM, operated by the US Air Force (USAF), collided in midair near Moncks Corner, South Carolina. The private pilot and passenger aboard the Cessna died, and the Cessna was destroyed during the collision. The damaged F-16 continued to fly for about 2 1/2 minutes, during which the pilot activated the airplane's ejection system. The F-16 pilot landed safely using a parachute and incurred minor injuries, and the F-16 was destroyed after its subsequent collision with terrain and postimpact fire. Visual meteorological conditions prevailed at the time of the accident. No flight plan was filed for the Cessna, which departed from Berkeley County Airport (MKS), Moncks Corner, South Carolina, about 1057, and was destined for Grand Strand Airport, North Myrtle Beach, South Carolina. The personal flight was conducted under the provisions of 14 Code of Federal Regulations (CFR) Part 91. The F-16 was operating on an instrument flight rules (IFR) flight plan and had departed from Shaw Air Force Base (SSC), Sumter, South Carolina, about 1020.

Air Force F-16

According to the USAF, the F-16 pilot was assigned as pilot-in-command for a single-ship, operational check flight to verify the completion of recent corrective maintenance. The flight itinerary included practice instrument approaches at Myrtle Beach International Airport (MYR), South Carolina, and Charleston Air Force Base/International Airport (CHS), Charleston, South Carolina, before returning to SSC. Since the flight was single ship and single pilot, the pilot performed an individual flight briefing using the personal briefing guide. (The Shaw General Briefing Guide is a local USAF document that F-16 pilots use to prepare for their missions.) Before departure, squadron personnel briefed the pilot on a range of subjects, including parking location, maintenance issues, aircraft configuration, notices to airmen, weather, and the mission timeline.

After departing from SSC, the F-16 proceeded to MYR, where the pilot conducted two practice instrument approaches before continuing to CHS. According to air traffic control (ATC) radar and voice communication data provided by the Federal Aviation Administration (FAA), the F-16 pilot contacted the approach controller at CHS about 1052 and requested to perform a practice tactical air navigation system (TACAN) instrument approach to runway 15. The controller instructed the F-16 pilot to fly a heading of 260° to intercept the final approach course. About 1055, the controller instructed the F-16 pilot to descend from 6,000 ft to 1,600 ft. About that time, the F-16 was located about 34 nautical miles (nm) northeast of CHS.

Cessna

Recorded airport surveillance video showed that the Cessna, which was based at MKS, departed from runway 23. At 1057:41, a radar target displaying a visual flight rules (VFR) transponder code of 1200,

and later correlated to be the accident Cessna, appeared in the vicinity of the departure end of runway 23 at MKS at an indicated altitude of 200 ft. The Cessna continued its climb and began tracking generally southeast over the next 3 minutes. For the duration of the flight, the pilot of the Cessna did not contact any ATC facilities, nor was he required to do so.

The Collision

The CHS automated radar terminal system (ARTS IIE) detected a conflict between the F-16 and the Cessna at 1059:59. According to recorded radar data, the conflict alert (CA) was presented on the radar display and aurally alarmed at 1100:13, when the F-16 and the Cessna were separated laterally by 3.5 nm and vertically by 400 ft.

At 1100:16, the CHS approach controller issued a traffic advisory advising the F-16 pilot of "traffic 12 o'clock, 2 miles, opposite direction, 1,200 [ft altitude] indicated, type unknown." At 1100:24, the F-16 pilot responded that he was "looking" for the traffic. At 1100:26, the controller advised the F-16 pilot, "turn left heading 180 if you don't have that traffic in sight." At 1100:30, the pilot asked, "confirm 2 miles?" At 1100:33, the controller stated, "if you don't have that traffic in sight turn left heading 180 immediately." As the controller was stating the instruction and over the next 18 seconds, the radar-derived ground track of the F-16 began turning southerly toward the designated heading.

At 1100:49, the radar target of the F-16 was 1/2 nm northeast of the Cessna, at an altitude of 1,500 ft, and was on an approximate track of 215°. At that time, the Cessna reported an altitude of 1,400 ft and was established on an approximate ground track of 110°. At 1100:53, the controller advised the F-16 pilot, "traffic passing below you one thousand four hundred [ft]." At 1100:54, the altitude of the F-16 remained at 1,500 ft, and the last radar return was received from the Cessna. Recorded radar data indicated that the ARTS IIE continued to provide a CA to the controller until 1101:00. The next radar target for the F-16 was not received until 1101:13. At 1101:19, the F-16 pilot transmitted a distress call, and no subsequent intelligible transmissions were received.

Several witnesses observed both airplanes in the moments leading up to the collision. One witness, located adjacent to the west branch of the Cooper River, noticed the Cessna flying overhead, roughly from west to east, and then observed the F-16 flying overhead, roughly from north to south. He estimated that the two airplanes collided at an altitude of about 900 ft. He further described that both airplanes were "very low." The F-16 struck the left side of the Cessna, and debris began falling. He reported that a large black cloud of smoke appeared after the collision but did not observe any fire. He stated that neither airplane appeared to conduct any evasive maneuvers before the collision. After the collision, the F-16 then "powered up," turned right, and flew southbound along the river.

Another witness reported that he was standing in his backyard overlooking the river. He watched as the Cessna flew by from west to east. He next saw the F-16 flying toward the Cessna, coming from the Cessna's left rear position, roughly north to south. When the F-16 collided with the left side of the Cessna, debris started falling, with some landing in his yard. He stated that it looked as if the F-16 tried to "pull up" just before impact. After the impact, the F-16 turned right and flew along the river to the south and out of sight. Once the F-16 was out of sight, he heard several loud "bang" noises.

ATC radar continued to track the F-16 as it proceeded on a southerly course. After it descended to 300

ft, radar contact was lost at 1103:17 in the vicinity of the F-16 crash site. The F-16 pilot used the airplane's emergency escape system (ejection seat) to egress, incurring minor injuries as he landed on the ground under canopy. He was subsequently met by first responders. Figure 1 shows the calculated flight track for the F-16 and the Cessna.



Figure 1. Calculated flight track for the F-16 (yellow) and the Cessna (orange). (The first witness is located north of the collision point, and the second witness is located southwest of the collision point.)

Pilot Information

Certificate:	Commercial; Military	Age:	34, Male
Airplane Rating(s):	Single-engine land; Multi-engine land	Seat Occupied:	Single
Other Aircraft Rating(s):	None	Restraint Used:	5-point
Instrument Rating(s):	Airplane	Second Pilot Present:	No
Instructor Rating(s):	None	Toxicology Performed:	No
Medical Certification:	None None	Last FAA Medical Exam:	
Occupational Pilot:	Yes	Last Flight Review or Equivalent:	
Flight Time:	(Estimated) 2383 hours (Total, all aircraft), 624 hours (Total, this make and model), 35 hours (Last 90 days, all aircraft), 24 hours (Last 30 days, all aircraft)		

F-16 Pilot

According to USAF personnel, the pilot of the F-16 was current and qualified in the accident airplane as a four-ship flight lead. His additional duties at the time of the accident included the position of 55th Fighter Squadron Chief of Mobility. At the time of the accident, he had accumulated 2,383 total hours of military flight experience, including 624 hours in the F-16. The pilot's total flight experience included 1,055 hours at the controls of the MQ-1B (Predator) and 456 hours at the controls of the MQ-9 (Reaper), both unmanned aerial vehicles. (The remaining hours were in USAF training aircraft and flight simulators.) His recent experience included 35 hours in the 90 days before the accident and 24 hours in the 30 days before the accident, all in the F-16. The USAF reported that the pilot was medically qualified for flight duty and was wearing contact lenses at the time of the accident.

The F-16 pilot's most recent instrument checkride was completed on August 25, 2014, and his most recent mission (tactical) checkride was completed on March 24, 2015. According to USAF records, none of the pilot's post-pilot training checkrides contained discrepancies or downgrades.

The F-16 pilot reported during a postaccident interview that he had accumulated about 50 hours of civilian flying experience and possessed an FAA-issued commercial pilot certificate obtained through 14 CFR 61.73. He had not flown civilian aircraft since he began initial USAF pilot training in July 2005.

Cessna Pilot

The pilot of the Cessna held a private pilot certificate with a rating for airplane single-engine land issued on December 29, 2014. His most recent, and only, FAA third-class medical certificate was issued on February 7, 2013, with no waivers or limitations. The pilot's personal flight logbook was recovered from the wreckage and contained detailed entries between May 2012 and July 5, 2015. As of the final entry, the pilot had accumulated 244 total flight hours, of which 239 hours were in the accident airplane make and model. He had flown 58 hours in the 90 days before the accident and 18 hours in the 30 days before the accident. Review of FAA records revealed no history of accidents, incidents, violations, or pending investigations.

The Cessna pilot's primary flight instructor indicated in a postaccident interview that the pilot was "very

careful" and "responsive." He stated that the pilot "enjoyed" talking to ATC and was aware of the benefits. During his instruction, he would contact ATC for flight-following without being prompted. A review of the pilot's logbook revealed that he communicated with SSC ATC on at least 9 occasions and CHS ATC at least 21 times.

Air Traffic Controller

The CHS approach controller was hired by the FAA in August 2006 and attended the FAA academy in Oklahoma City before working at the Oakland Air Route Traffic Control Center. She resigned from the FAA in September 2007 and was rehired in February 2008. She worked at CHS since her rehire. Before working for the FAA, she served as an air traffic controller in the USAF from 1998 to 2000.

The controller was qualified and current on all operating positions at CHS and held no other FAA certifications. Her most recent FAA second-class medical certificate was issued on May 21, 2014, with a requirement to wear glasses while providing ATC services. She was wearing glasses on the day of the accident.

On the day of the accident, the controller was working a regularly scheduled 0700 to 1500 shift. At the time of the accident, she was working the radar west position combined with the radar east position, which was the normal radar configuration at CHS. The radar assistant position, called radar handoff, was also staffed. About 1101, when the accident occurred, she had been working the radar west position for about 1 1/2 hours.

Aircraft and Owner/Operator Information

Aircraft Make:	LOCKHEED-MARTIN	Registration:	96-0085
Model/Series:	F-16CM	Aircraft Category:	Airplane
Year of Manufacture:	1999	Amateur Built:	
Airworthiness Certificate:	None	Serial Number:	96-0085
Landing Gear Type:	Retractable - Tricycle	Seats:	1
Date/Type of Last Inspection:	June 4, 2016 Continuous airworthiness	Certified Max Gross Wt.:	37000 lbs
Time Since Last Inspection:		Engines:	1 Turbo fan
Airframe Total Time:	4435 Hrs as of last inspection	Engine Manufacturer:	General Electric
ELT:	Installed, activated, did not aid in locating accident	Engine Model/Series:	F110-GE-129
Registered Owner:	United States Air Force	Rated Power:	29400 Lbs thrust
Operator:	United States Air Force	Operating Certificate(s) Held:	None

Cessna

The white- and red-colored Cessna 150M was a single-engine, high-wing airplane with a conventional

tail. It was equipped with a rotating beacon light, anticollision strobe lights, navigation position lights, and a landing light. The operational status of each lighting system at the time of the accident could not be determined. Review of the airplane's maintenance and airworthiness records revealed no evidence that any supplemental equipment, such as high intensity anticollision lights, had been installed after delivery to enhance its visual conspicuity. The airplane was not equipped with a traffic advisory system (TAS), traffic alert and collision avoidance system (TCAS), or automatic dependent surveillance-broadcast (ADS-B) equipment or displays.

The Cessna was equipped with a King KX 155 single VHF communication radio, a King KT 78 mode C transponder, and an Ameri-King AK-350 altitude encoder. Review of maintenance records revealed that the most recent transponder and encoder tests per the requirements of 14 CFR 91.413 were completed on September 8, 2008. On July 20, 2012, an overhauled transponder and new altitude encoder of the same makes and models were installed. The units were ground tested in accordance with the procedures outlined in their respective maintenance manuals, but the maintenance records did not note any tests in accordance with 14 CFR 91.413. The pitot/static system was most recently tested per the requirements of 14 CFR 91.411 on April 11, 2013. The Cessna's most recent annual inspection was completed on October 14, 2014. At the time of the inspection, the airframe had accumulated 3,651 total hours of operation.

Air Force F-16

The gray-colored F-16 was a single-seat, turbofan-powered fighter airplane. Its most recent 400 hour phase inspection was completed on June 4, 2014, and it had accumulated 237 flight hours since that time. After a flight on June 11, 2015, USAF maintenance personnel completed work on the airplane's flight control system and subsequently cleared the airplane to return to service on July 2, 2015. At the time of the accident, the airframe had accumulated 4,435 total hours of operation. The airplane was not equipped with a TAS, TCAS, or ADS-B equipment or displays.

The USAF provided general information about the limitations of the F-16 radar and "identification friend or foe" (IFF) systems (more specific information is sensitive). The F-16 was equipped with a radar unit installed in the nose of the airplane that the pilot could use to locate and "lock on" to other aircraft. The radar was forward looking and limited to a search area spanning 120° directly in front of the F-16 (60° either side of center). The radar was also limited by the size of the target and was normally used to identify targets within a 40-mile range, but other settings were available. According to USAF personnel, the radar unit was designed to acquire fast moving enemy aircraft (not slow-moving, small aircraft). USAF personnel did not believe the radar would locate a small general aviation aircraft at takeoff or climb speed. The radar acquired targets by direct energy return off the target aircraft's surface and used aircraft closure rate rather than the airspeed of the other aircraft to filter out slow-moving targets.

When operating in search target acquisition mode, traffic was displayed as a small, white square target on the radar's multifunction displays (MFD), which were located on the cockpit instrument panel, near the pilot's knees. If a target existed, a subsequent sweep of the radar would reveal a new target, and the previous image would be lighter in intensity. There were no aural alerts if a new target appeared. The pilot could place a cursor over the target and "lock" the target on the radar if he/she chose. After locking on, the pilot could obtain the mean sea level (msl) altitude of the target.

The F-16 was also equipped with an IFF interrogator. Targets identified by this system would be displayed on the MFD, but it was not an integral part of the radar. The IFF interrogator could be programmed to request specific types of responses (1 to 4); most civilian aircraft with an operating ATC transponder would provide a "type 3" response. To receive any type of response, the F-16 pilot would have to manually initiate the interrogation process, which takes about 8 to 10 seconds to sweep and display all four types of responses, each being displayed for about 2 seconds.

The F-16 was equipped with a basic autopilot providing attitude hold, heading select, and steering select in the roll axis, and attitude hold and altitude hold in the pitch axis. There was no capability for autopilot-coupled instrument approaches. There were three bank settings: go-to heading, selected steer point, and hold bank angle. While the autopilot was engaged in heading select mode and a new heading was selected, the airplane would turn at about a bank angle not to exceed 30°. According to the F-16 flight manual, the autopilot was able to maintain altitude within ±100 ft under normal cruise conditions. Manual inputs through the control stick would override autopilot functions. If specific limits were exceeded during manual override, the autopilot would disconnect.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	Condition of Light:	Day
Observation Facility, Elevation:	KMKS, 73 ft msl	Distance from Accident Site:	2 Nautical Miles
Observation Time:	10:55 Local	Direction from Accident Site:	302°
Lowest Cloud Condition:	Scattered / 2600 ft AGL	Visibility	10 miles
Lowest Ceiling:	None	Visibility (RVR):	
Wind Speed/Gusts:	/	Turbulence Type Forecast/Actual:	/
Wind Direction:		Turbulence Severity Forecast/Actual:	/
Altimeter Setting:	30.14 inches Hg	Temperature/Dew Point:	30°C / 22°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	Sumter, SC (SSC)	Type of Flight Plan Filed:	IFR
Destination:	Sumter, SC (SSC)	Type of Clearance:	IFR
Departure Time:	10:20 Local	Type of Airspace:	Class E

The area forecast that included eastern South Carolina was issued at 0445 and forecasted scattered clouds between 3,000 and 4,000 ft msl, with scattered cirrus clouds and widely scattered light rain showers and thunderstorms after 1100.

The closest facility disseminating a terminal aerodrome forecast was CHS. The last forecast published before the accident was issued at 0723. The forecast weather conditions beginning at 0800 and continuing through 1300 included variable winds at 4 knots, greater than 6 statute miles visibility, and few clouds at 4,000 ft above ground level (agl).

Review of weather radar imagery showed no precipitation in the vicinity of the accident site about the time of the accident.

The weather conditions reported at MKS at 1055 included calm wind, 10 statute miles visibility, scattered clouds at 2,600 ft agl, a temperature of 30° C, a dew point of 22° C, and an altimeter setting of 30.15 inches of mercury.

The weather conditions reported at CHS at 1055 included wind from 220° true at 7 knots, 10 statute miles visibility, scattered clouds at 4,000 ft agl, a temperature of 30° C, a dew point of 22° C, and an altimeter setting of 30.15 inches of mercury.

At the time of the accident, the sun was about 57° above the horizon at an azimuth of about 99°.

Airport Information

Airport:	BERKELEY COUNTY MKS	Runway Surface Type:	
Airport Elevation:	73 ft msl	Runway Surface Condition:	
Runway Used:		IFR Approach:	None
Runway Length/Width:		VFR Approach/Landing:	None

CHS has two intersecting runways oriented in a 15/33 and 03/21 configuration, at an elevation of 46 ft. The airport is served by numerous instrument approaches, including a VOR [very high omnidirectional range]/DME [distance measuring equipment] or TACAN approach to runway 15. The minimum altitude for the intermediate portion of the approach was 1,600 ft msl, while the minimum crossing altitude at the final approach fix, located 2.8 nm from the runway 15 threshold, was 1,100 ft msl.

ATC services at the airport are provided continuously by a combined ATC tower and terminal radar approach control (TRACON) facility. The CHS TRACON airspace extends for an approximate 40-nm radius from CHS, from the surface to 10,000 ft msl. Radar data are displayed to air traffic controllers at CHS via the ARTS IIE, with the radar feed from the airport surveillance radar (ASR-9), located at CHS.

The airport is surrounded by class C airspace, defined as that airspace extending from the surface up to and including 4,000 ft msl, within a 5-nm radius of CHS and that airspace extending from 1,200 ft msl up to and including 4,000 ft msl, within a 10-mile radius of CHS. There is no specific pilot certification required to operate within the class C airspace, but, according to 14 CFR 91.215, aircraft are required to be equipped with a two-way radio with an operable radar beacon transponder with automatic altitude reporting equipment. According to 14 CFR 91.130, before entering the class C airspace, two-way radio communication must be established and subsequently maintained with the ATC facility providing services.

Pilots requesting ATC services at CHS are required to contact the ATC facility on the publicized radio frequency and provide their position, altitude, radar beacon code, destination, and the nature of their request. Radio contact should be initiated far enough from the class C airspace boundary to preclude entering class C airspace before two-way radio communications are established. Beyond the class C airspace is an outer area that extends to a 20-nm radius of the airport. There were no specific communications or transponder requirements to operate in this area; however, approach control services could still be provided by ATC when operating in the outer area.

MKS, the Cessna's departure airport, is located about 17 nm north of CHS and is outside the CHS class C airspace. The airspace surrounding MKS and encompassing the collision location is designated as class E and extends from 700 ft agl to 17,999 ft msl. There are no two-way radio communication or transponder use requirements for operation in class E airspace. The established minimum vectoring altitude for ATC in this area is 1,600 ft, which represented the lowest altitude available to controllers when providing radar vectors to aircraft operating under IFR. Figure 2 shows an FAA sectional chart depicting CHS and class C airspace, MKS, and the approximate collision location.



Figure 2. FAA sectional aeronautical chart view depicting CHS and class C airspace, MKS, and the approximate collision location. (Not for navigational use.)

An instrument military training route (MTR), IR-18, transits generally south to north with an altitude structure of 5,000 to 7,000 ft msl, and is located about 1 nm east of MKS. A visual MTR, VR-1040/1041, transits generally east to west with an altitude structure of 200 to 1,500 ft agl and is located about 5 nm northwest of MKS. (The F-16 was not operating on either of these MTRs.) Several military operations areas, two USAF airbases, and a National Guard airbase are located within 60 nm of MKS.

The airport/facility directory entry for MKS did not provide any warning or cautions regarding low altitude, high speed military air traffic in the vicinity of the airport.

Wreckage and Impact Information

Crew Injuries:	1 Minor	Aircraft Damage:	Destroyed
Passenger Injuries:		Aircraft Fire:	On-ground
Ground Injuries:		Aircraft Explosion:	None
Total Injuries:	1 Minor	Latitude, Longitude:	33.160831,-79.991111

Cessna

The wreckage of the Cessna was recovered in the vicinity of its last observed radar target, over the west branch of the Cooper River. Components from both airplanes were spread over an area to the north and west of that point, extending for about 1,200 ft. The largest portions of the Cessna's airframe included a relatively intact portion of the fuselage aft of the main landing gear and the separate left and right wings, all of which were within 500 ft northwest of the airplane's final radar-observed position. Portions of the cabin interior, instrument panel, fuel system, and engine firewall were found distributed throughout the site. The engine, propeller, and nose landing gear assembly were not recovered. The lower aft engine cowling of the F-16 was also recovered in the immediate vicinity of the Cessna's aft fuselage, while the F-16's engine augmentor was recovered about 1,500 ft southwest. Small pieces of the F-16's airframe were also distributed throughout the accident site.

Both of the Cessna's wings displayed uniform leading-edge crush damage throughout their spans that was oriented aft and upward. Paint transfer and rub markings (consistent with paint from the F-16) oriented from left to right were observed along the upper forward surfaces of both wings. Both fuel tanks were ruptured, and evidence of heat damage and thermal paint blistering were observed on the upper surface of the right wing. Flight control continuity was traced through overload-type cable separations from the cabin area to each flight control surface. Measurement of the pitch trim actuator showed a position consistent with a 3°-to-4° deflection of the tab in the nose down direction, and measurement of the flap actuator showed a position consistent with the flaps having been in the retracted position.

Air Force F-16

The F-16 wreckage site was located about 6 nm south of the Cessna wreckage site. The F-16 wreckage path was about 700 ft long and oriented roughly 215°, with portions of the airframe distributed along the wreckage path. The wreckage displayed significant ground impact and postimpact fire-related damage.

Flight recorders

A crash-survivable memory unit (CSMU) was recovered from the wreckage of the F-16, and the digital flight control system seat data recorder was recovered from the airplane's ejection seat. Both memory units were forwarded to the airframe manufacturer for data extraction under the supervision of a National Transportation Safety Board (NTSB) vehicle recorder specialist. The data were downloaded normally with no anomalies noted.

Medical and Pathological Information

The Department of Pathology and Lab Medicine, Medical University of South Carolina, determined that the cause of death for both occupants of the Cessna was "blunt trauma." The FAA's Civil Aerospace Medical Institute performed postaccident toxicological testing on tissue specimens from the Cessna pilot. The specimens tested negative for a wide range of drugs, including major drugs of abuse. Although the specimens tested positive for ethanol, the levels of ethanol were consistent with postmortem ethanol production.

A Department of Defense Armed Forces medical examiner scientist performed postaccident toxicological testing on blood and urine specimens from the F-16 pilot, and the specimens tested negative for carbon monoxide, ethanol, and major drugs of abuse.

Tests and Research

Aircraft Performance and Cockpit Visibility Study

The NTSB's investigation examined the ability of the Cessna and F-16 pilots to see and avoid the other aircraft. To determine approximately how each aircraft would appear in the pilots' fields of view, the position of the "target" aircraft in a reference frame attached to the "viewing" aircraft must be calculated. This calculation depends on the positions and orientation (pitch, roll, and yaw angles) of each aircraft, as well as the location of the pilots' eyes relative to the cockpit windows. Data for the F-16 were derived from its CSMU, while orientation information for the Cessna was estimated based on an analysis of the radar data.

After the position and orientation of each airplane were determined, the position of each airplane in the body axis system of the other was calculated. These relative positions then determined where the "target" airplanes likely would have appeared in the fields of vision of the pilots of the "viewing" airplanes. The study assumed a nominal pilot seating (and eye) position in each cockpit and evaluated a matrix of eye displacements from the nominal eye position. For this study, the relative positions of the two airplanes were calculated beginning when the Cessna became visible on radar and then at 1-second intervals up to the collision. The time, location, and altitude of the collision were determined based on extrapolation of the radar and F-16 CSMU data and on the location of the main Cessna wreckage. The

locations of the structures and transparencies of the F-16 and Cessna in the pilots' fields of view were determined from the interior and exterior dimensions of representative airplanes, as measured using a laser scanner. The structural obscurations to each pilot's view were merged with the calculated relative position data and are discussed below. The variations in eye position changed the timing of the obscurations of the opposite aircraft by less than +/-1.5 seconds at any given point.

At 1100:16, when the controller provided the initial traffic advisory to the F-16 pilot, the F-16 was in a wings-level attitude, at an altitude of about 1,570 ft, on a ground track of 252°, and at a ground speed of 253 knots. The Cessna's calculated position was 3.25 nm from the F-16, at a position directly ahead (about 12 o'clock), and at an altitude of roughly 1,200 ft. The Cessna's ground track was 109°, and it was climbing at a rate of about 240 ft per minute. The aircraft performance and cockpit visibility study showed that, at 1100:18, the Cessna would have appeared to the F-16 pilot as a very small, stationary object just above the horizon and near the center of the airplane's heads up display (HUD) (see figure 3a); the F-16 would have appeared to the Cessna pilot as a small, stationary object just above the horizon, but outside of the left cockpit door window, near the forward vertical post of the door frame (see figure 3b).



Figure 3a. Simulated cockpit visibility from the F-16 at 1100:18, when the airplanes were 3.1 nm apart. (Transparent shadow masks depict areas where visibility is obscured by airplane structure.)

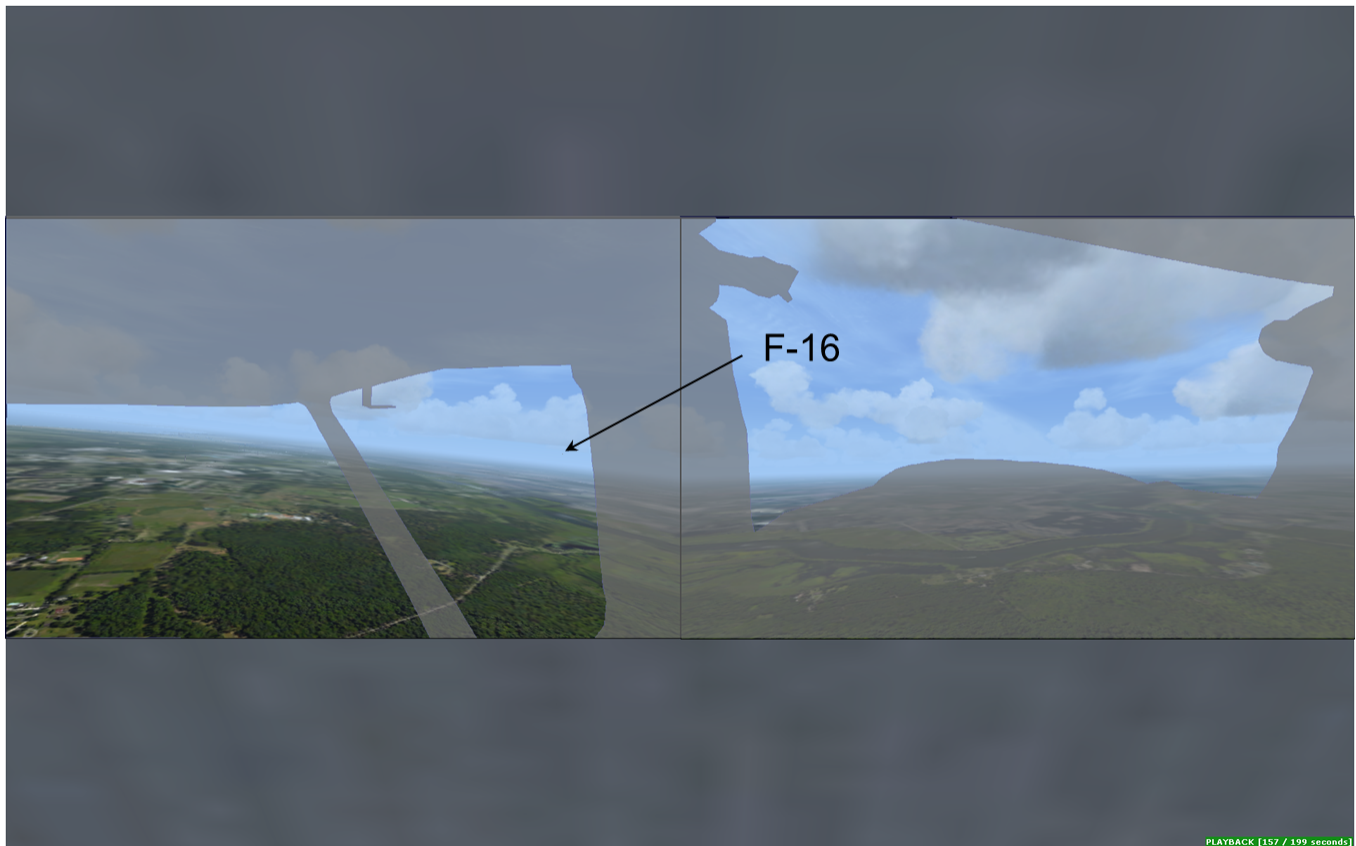


Figure 3b. Simulated cockpit visibility from the Cessna at 1100:18, when the airplanes were 3.1 nm apart. (Transparent shadow masks depict areas where visibility is obscured by airplane structure.)

At 1100:26, when the controller advised the F-16 pilot, "turn left heading 180 if you don't have that traffic in sight," the relative positions changed slightly, with the Cessna moving slightly to the left but still remaining within the F-16's HUD, and the F-16 moving slightly aft in the Cessna pilot's left window.

At 1100:33, when the controller stated, "If you don't have that traffic in sight turn left heading 180 immediately" and as the F-16 began banking to the left, the F-16 pilot's view of the Cessna would have been obscured behind the left structural frame of the HUD. The position of the F-16 would have remained unchanged to the Cessna pilot.

At 1100:49, as the F-16 was executing its left turn at a bank angle of 30°, the Cessna would have become more discernable in the lower right portion of the F 16 pilot's HUD (see figure 4a). The F-16 would also have become more discernable, visible through the Cessna pilot's left window at a point just forward of the wing strut attachment point (see figure 4b).



Figure 4a. Simulated cockpit visibility from the F-16 at 1100:49, when the airplanes were 0.6 nm apart.

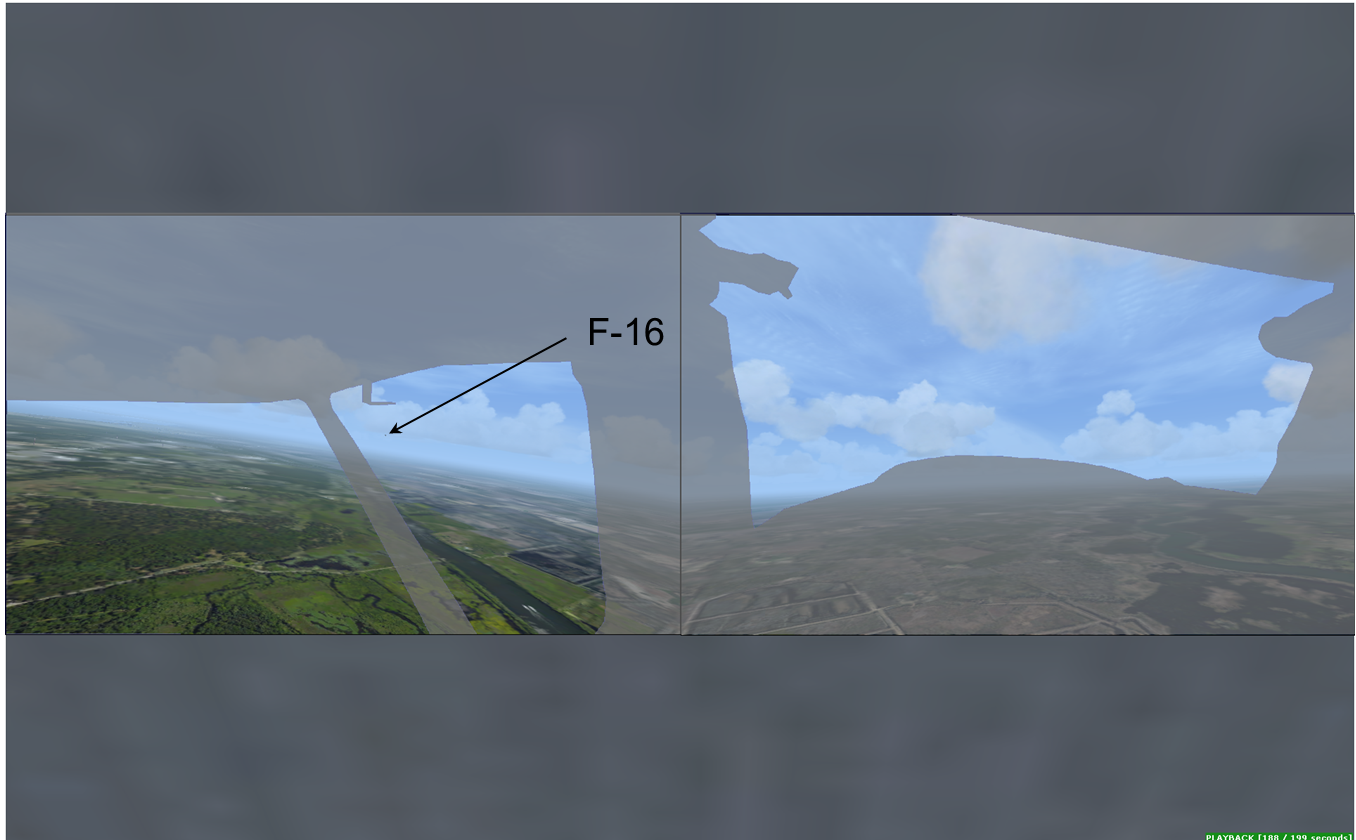


Figure 4b. Simulated cockpit visibility from the Cessna at 1100:49, when the airplanes were 0.6 nm apart.

At 1100:53, when the controller advised the F-16 pilot, "traffic passing below you" at 1,400 ft, the F-16 was flying at an altitude of 1,480 ft, while the estimated altitude of the Cessna was 1,440 ft. The closure rate of both airplanes at this point was 264 knots. The Cessna would have been visible to the right of the structural frame of the F 16's HUD, while the F-16 would have appeared to the Cessna pilot in largely the same position but with a more defined shape.

Over the next 3 seconds, the airplanes continued to approach each other, with the F-16 approaching the Cessna from its left and slightly above. The Cessna would have been completely obscured by the lower right cockpit structure of the F-16, as the airplane banked in its turn to the left (see figure 5a). The F 16 would have become partially obscured by the left wing strut (see figure 5b).



Figure 5a. Simulated cockpit visibility from the F-16 at 1100:56, when the airplanes were 260 ft apart.



Figure 5b. Simulated cockpit visibility from the Cessna at 1100:56, when the airplanes were 260 ft apart.

In-Cockpit Traffic Display Simulation

The FAA's Aeronautical Information Manual (AIM) (dated December 10, 2015, and revised on May 26, 2016), paragraph 4-5-7, states that ADS B is a surveillance technology deployed throughout the National Airspace System. The ADS-B system is composed of aircraft avionics and a ground infrastructure. Onboard avionics determine the position of an aircraft by using the GPS and transmitting its position along with additional information about the aircraft to ground stations for use by ATC and other ADS-B services. This information is transmitted at a rate of approximately once per second. ADS-B avionics can have the ability to both transmit and receive information. The transmission of ADS-B information from an aircraft is known as ADS B Out. The receipt of ADS-B information by an aircraft is known as ADS-B In. On January 1, 2020, all aircraft operating within the airspace defined in 14 CFR 91.225 will be required to transmit the information defined in 14 CFR 91.227 using ADS-B Out avionics.

The ADS-B capabilities that enhance a pilot's awareness of airborne traffic in their vicinity are described in FAA Advisory Circular (AC) 20-172B, "Airworthiness Approval for ADS-B In Systems and Applications." Per the AC, this capability allows an appropriately equipped aircraft to receive and display another aircraft's ADS-B Out information, as well as ground station broadcast information, from services like traffic information services-broadcast (TIS-B) and automatic dependent surveillance-rebroadcast (ADS-R). The received information is processed by onboard avionics and presented to the flight crew on a display. ADS-B In avionics enable a number of aircraft surveillance applications and

can enhance visual acquisition by displaying nearby traffic on a plan view (bird's eye view) relative to own-ship. The traffic information assists pilots in visually acquiring traffic out the window while airborne but does not relieve them of see-and-avoid responsibilities. Additionally, the information derived through ADS-B In applications can be used to provide voice annunciations to flight crews to draw attention to alerted traffic.

The images from the NTSB's in-cockpit traffic display simulation presented in figures 6 and 7 are representative of the minimum operations specifications for such displays contained in RTCA document DO-317B but do not duplicate the implementation or presentation of any particular operational display exactly. The actual images presented to a pilot depend on the range scale and background graphics selected by the pilot (which could reflect various implementations and combinations of moving maps, terrain elevation data, and weather information, rather than the simple black background presented here).

For this accident, simulated in-cockpit displays of traffic information for both the F-16 and Cessna were created based on the TIS-B information that would have been displayed to the pilot of each airplane assuming that both aircraft were equipped with ADS-B In capability and avionics capable of displaying and aurally annunciating the traffic information. In addition, the simulation assumes that at least one ADS-B Out equipped aircraft was operating in the vicinity of the two accident aircraft in order to trigger the broadcast of TIS-B information from a ground station, as currently, aircraft equipped with only ADS-B In cannot trigger the broadcast of this information.

The NTSB's in-cockpit traffic display simulation for the F-16 indicates that at 1058:06, an open (outlined), cyan-colored, arrowhead-shaped target representing the Cessna would have appeared at the F-16's 12 o'clock position (straight ahead), 15 nm from and 1,300 ft below the F-16. The Cessna would have been the only target within that range from that time up to the time of the collision at 1100:57. As the airplanes approached each other, the Cessna target would have been shown turning left from west to east and then approaching the F-16 from its 12 o'clock position, slightly to the right of the F-16's flightpath, and climbing. The heading depicted by the Cessna symbol as the aircraft converged would have indicated that the Cessna's projected flightpath would cross the F-16's flightpath from right to left. At 1059:47, the Cessna symbol would have changed from an open cyan arrowhead to a filled cyan arrowhead, as the Cessna closed within 6 nm horizontally and 600 ft vertically of the F-16.

At 1100:35, as the F-16 banked into its left turn toward the south, the pilot would have received an aural alert associated with the Cessna, which by then had closed within 2 nm horizontally and 300 ft vertically. The aural alert would have advised, "Traffic, 12 o'clock, low, 2 miles." As shown in figure 6, the Cessna symbol would have changed to a filled yellow arrowhead, enclosed by a yellow circle. As the F-16 continued in its left turn, the Cessna target would have rotated to the right side of the F-16's projected course, with its heading still projected to intercept that course. At 1100:56, one second before the collision, the F-16 would have received a second aural alert of "Traffic, 2 o'clock, same altitude, zero miles." The symbol representing the Cessna would have depicted it 100 ft below the F-16 (see figure 6).

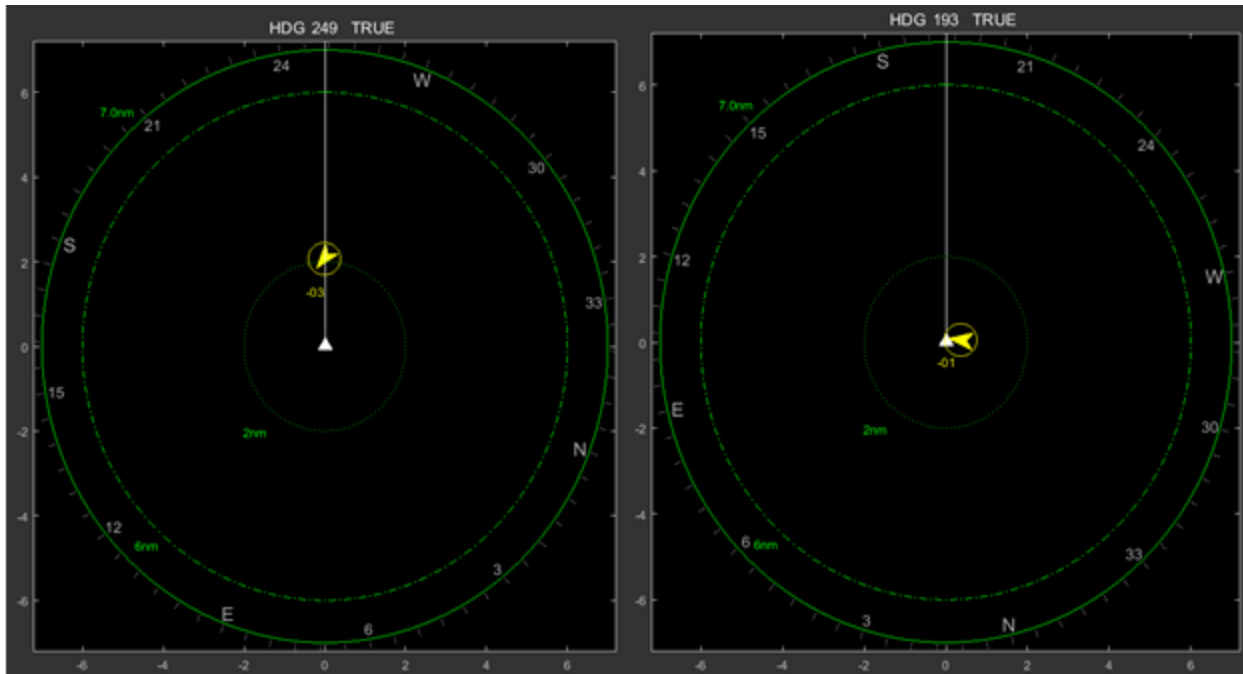


Figure 6. Simulated in-cockpit traffic display for the F-16 at 1100:35 (left) and 1100:56 (right).

The in-cockpit traffic display simulation for the Cessna indicates that at 1058:05, an open cyan target representing the F-16 would have appeared at the Cessna's 8 o'clock position, 15 nm from and 1,300 ft above the Cessna. The F-16 would have been one of two targets within that range from that time up to the time of the collision at 1100:57. The other target would have appeared between the Cessna's 12 and 1 o'clock position, about 11 nm from and 1,300 ft above the Cessna. As the Cessna turned left toward the east, the F-16 target would have rotated to the Cessna's 11 o'clock position and been depicted flying toward the Cessna. The other aircraft would have rotated to the Cessna's 3 o'clock position and been depicted flying away from the Cessna. At 1059:47, the F-16 symbol would have changed from an open cyan arrowhead to a filled cyan arrowhead, as the F-16 closed within 6 nm horizontally and 600 ft vertically of the Cessna.

At 1100:35, as the F-16 banked into its left turn toward the south, the Cessna pilot would have received an aural alert associated with the F-16, which by then had closed within 2 nm horizontally and 300 ft vertically. The aural alert would have advised, "Traffic, 11 o'clock, high, 1 mile." As shown in figure 7, the F-16 symbol would have changed to a filled yellow arrowhead, enclosed by a yellow circle. The Cessna would not have received a second aural alert for the F-16, but the F-16 symbol would have remained in alert status (filled yellow arrowhead enclosed by a yellow circle) until the collision.

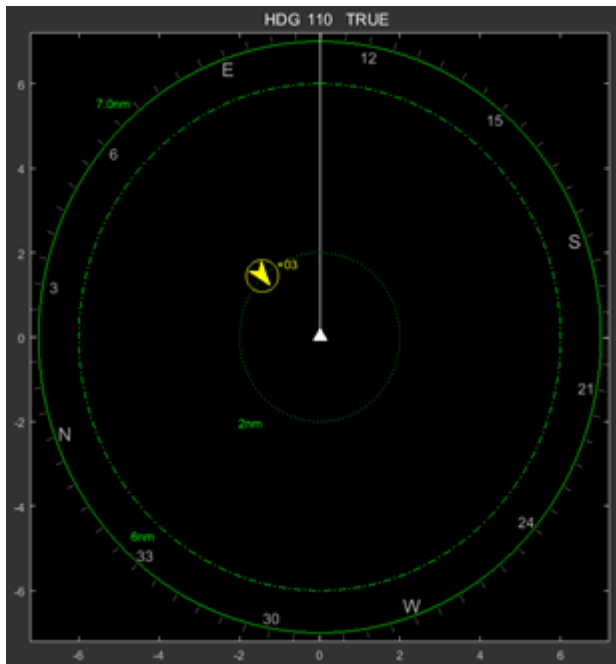


Figure 7. Simulated in-cockpit traffic display for the Cessna at 1100:35.

Organizational and Management Information

USAF Mid-Air Collision Avoidance Program

The USAF has a Mid-Air Collision Avoidance (MACA) program detailed in Air Force Instruction (AFI) 91-202, dated June 24, 2015. According to AFI 91-202, USAF flying units must have a written MACA program, and the unit safety office is responsible for its creation, documentation, and upkeep. The 20th Fighter Wing (FW) Safety Office administered the Shaw Air Force Base MACA program. The required elements are a MACA pamphlet and a poster, primarily designed for use in the civilian community. The program includes civilian outreach and incorporates interaction with pilot advocacy organizations, the FAA, local airports, and fixed base operators. The 20th FW Safety Office also maintains a public website populated with the MACA program products and other safety information. According to 20th FW Safety Office personnel, activities related to MACA are coordinated with two other military bases: Charleston Joint Base and McEntire Joint National Guard Base. The Charleston Joint Base Flight Safety office held MACA seminars at MKS in June 2012, January 2014, and March 2015.

Additional Information

Postaccident Interviews

F-16 Pilot

Members of the USAF Accident Investigation Board interviewed the F-16 pilot after the accident. He reported that he had the radar configured for a 20- and 40-mile range, manually alternating back and forth, and could not recall if his IFF interrogator was set up to receive civilian transponder replies. He was using a scan pattern that included looking outside; checking instruments for altitude, airspeed, and heading; and checking the radar display.

The F-16 pilot indicated that he had acquired and locked on a radar target 20 miles away. He stated that shortly thereafter, the controller issued an alert for traffic at his 12 o'clock position, 2 miles away, at 1,200 ft. He remarked that a 2-mile call was the "...closest call I've ever received" and that it was "...a big alert for me." He then asked the controller to "confirm two miles"; he indicated in a postaccident interview that he asked that question because he was looking at traffic on his radar at 20 miles away. He then began aggressively looking to visually acquire the airplane and recalled a command from the controller to turn left "immediately" to a heading of 180°. He stated that he used the autopilot to execute the turn so that he could continue to search outside for the traffic. The autopilot turn used 30° of bank and standard rate, or 3° per second of turn. He continued to search for the traffic until he observed the Cessna directly in front of his airplane, "within 500 feet." He then applied full aft control stick inputs to avoid a collision, but it was "too late." He estimated that the time from initial sighting of the Cessna to the impact was less than 1 second. After the collision, he attempted to maintain control of his airplane; however, once he determined that continued controlled flight was not possible, he initiated his emergency egress.

Air Traffic Controller

The air traffic controller described the traffic on the day of the accident as light and routine, with nothing out of the ordinary. Several USAF fighter aircraft from SSC were making approaches to CHS when the F-16 entered the airspace from the northeast and requested a TACAN approach. The controller told the pilot to expect the requested approach and provided climb-out instructions after completing the approach. She issued a radar vector of 260° to intercept the 10- to 15-mile final approach course for the instrument approach. The intent of this vector was to keep the F-16 south of, and to avoid overflying, MKS. The controller stated that she then directed the F-16 to descend and maintain 1,600 ft and was "pretty much done with him" while she worked other traffic, including a flight of two other F 16s. She had descended the accident airplane to 1,600 ft because that was the minimum vectoring altitude at CHS. She stated that this was her usual technique; getting aircraft to their final altitude quickly allowed her more efficient use of her time.

When the controller initially noticed the Cessna depart from MKS, she thought that it would remain in the local VFR traffic pattern. She described that, generally, pattern traffic at MKS was rare and, when present, typically stayed below 1,000 ft. She then descended the other two aircraft flight of F-16s to sequence them behind the accident F-16 and to get them around other traffic. Shortly after, she asked the two-aircraft flight to expedite its descent to 3,000 ft and noticed that the Cessna was climbing above 1,000 ft. She responded by advising the F-16 pilot, hoping that he would be able to visually acquire the traffic, but the F-16 pilot did not report the traffic in sight. She advised the F-16 pilot to turn left heading 180 if he did not have the traffic in sight.

As the radar targets were continuing to close on one another, she directed the F-16 pilot that if he did not have the traffic in sight to turn left heading 180 immediately. She reported that the 180 heading assignment was preferred over a turn to the north because the turn was quicker, and she believed that "fighters could turn on a dime." She stated that her expectation was that the word "immediately" meant to react now and that, with a fighter aircraft, it meant to do a "max performance turn" to the heading. She stated that she did not recall seeing or hearing a CA generated by the ATC radar system. The controller indicated in a postaccident interview that she chose not to direct the F 16 to climb because the altitude indicated for the Cessna's radar target was unconfirmed.

The controller advised the F-16 pilot that the Cessna had passed below him and thought the two aircraft were clear of each other until she saw the Cessna's radar target disappear followed by the F 16 pilot's distress call. She briefly initiated a call to the pilot and then turned to the radar handoff controller and told him "I don't know what to do." The radar handoff controller advised her to "separate what you've got."

ATC Radar Equipment

The radar display system in use at CHS at the time of this accident, ARTS IIE, is designed to support one or two sensors and up to 22 displays in two different configurations and can process 256 simultaneous tracks per sensor. At the time of the accident, there were no known or reported equipment discrepancies with the ARTS IIE system that would have affected the controller's ability to provide ATC services.

The ARTS IIE has numerous capabilities and functions to help controllers with strategic and tactical decision-making. One of these functions is the CA/mode C intruder, which provides controllers with visual and immutable aural warnings for aircraft that are or will be in dangerous proximity to one another. A CA provides a visual presentation on the radar scope display associated with the conflicting aircraft and an aural alarm when conditions warrant. These conditions are based on vertical and horizontal parameters established for the environment in which the aircraft are operating. For example, in an en route environment where aircraft are operating at higher altitudes and faster speeds, the parameters would be more sensitive when compared to an airport environment, where aircraft operate closer to each other and at lower speeds. For a predicted alert, the ARTS IIE evaluates a developing conflict for two of three consecutive radar sweeps. The average sweep of an ASR (a 360° scan) takes about 5 seconds.

The CHS ARTS IIE detected the conflict between the F-16 and the Cessna at 1059:59, and the CA was presented on the radar scope with an accompanying aural alert at 1100:13. The ARTS IIE continued to provide a CA to the controller until 1101:00. As the controller stated in her postaccident interview, she did not recall seeing or hearing the CA, but review of archived ATC audio revealed that her initial traffic advisory to the F-16 began at 1100:16, 3 seconds after the CA alerted. A postaccident test of the CA alarm at CHS revealed that it worked properly.

FAA and USAF Rules, Regulations, and Guidance to Pilots

Title 14 CFR 91.113 addresses aircraft right-of-way rules and states, in part, the following:

(b) General. When weather conditions permit, regardless of whether an operation is conducted under instrument flight rules or visual flight rules, vigilance shall be maintained by each person operating an aircraft so as to see and avoid other aircraft.

The FAA's AIM, dated April 3, 2014, paragraph 5-5-8, includes pilot procedures for see-and-avoid while in flight and states, "When meteorological conditions permit, regardless of type of flight plan or whether or not under control of a radar facility, the pilot is responsible to see and avoid other traffic, terrain, or obstacles."

The AIM, paragraph 4-1-9, also describes operations to/from airports without an operating control tower and the use of a common traffic advisory frequency (CTAF) and states, in part, the following:

a. Airport Operations Without Operating Control Tower

1. There is no substitute for alertness while in the vicinity of an airport. It is essential that pilots be alert and look for other traffic and exchange traffic information when approaching or departing an airport without an operating control tower...To achieve the greatest degree of safety, it is essential that all radio-equipped aircraft transmit/receive on a common frequency identified for the purpose of airport advisories.

b. Communicating on a Common Frequency

The key to communicating at an airport without an operating control tower is selection of the correct common frequency...A CTAF is a frequency designated for the purpose of carrying out airport advisory practices while operating to or from an airport without an operating control tower.

The AIM describes the recommended communication procedures regarding departure aircraft on the CTAF and states, "Pilots of inbound traffic should monitor and communicate as appropriate on the designated CTAF from 10 miles to landing. Pilots of departing aircraft should monitor/communicate on the appropriate frequency from start-up, during taxi, and until 10 miles from the airport unless the CFRs or local procedures require otherwise."

The AIM, paragraph 5-5-10, describes the manner in which pilots could expect to receive traffic advisories from ATC and states the following:

a. Pilot.

1. Acknowledges receipt of traffic advisories.
2. Informs controller if traffic in sight.
3. Advises ATC if a vector to avoid traffic is desired.
4. Does not expect to receive radar traffic advisories on all traffic. Some aircraft may not appear on the radar display. Be aware that the controller may be occupied with higher priority duties and unable to issue traffic information for a variety of reasons.
5. Advises controller if service is not desired.

b. Controller.

1. Issues radar traffic to the maximum extent consistent with higher priority duties except in Class A airspace.
2. Provides vectors to assist aircraft to avoid observed traffic when requested by the pilot.
3. Issues traffic information to aircraft in the Class B, Class C, and Class D surface areas for sequencing purposes.
4. Controllers are required to issue to each aircraft operating on intersecting or nonintersecting converging runways where projected flight paths will cross.

The Pilot's Handbook of Aeronautical Knowledge (FAA-H-8083-24A), section 13, addresses scanning procedures for visually acquiring traffic:

The pilot can contribute to collision avoidance by being alert and scanning for other aircraft. This is particularly important in the vicinity of an airport.

Effective scanning is accomplished with a series of short, regularly spaced eye movements that bring successive areas of the sky into the central visual field. Each movement should not exceed 10°, and each should be observed for at least 1 second to enable detection. Although back and forth eye movements seem preferred by most pilots, each pilot should develop a scanning pattern that is most comfortable and then adhere to it to assure optimum scanning. Even if entitled to the right-of-way, a pilot should yield if another aircraft seems too close.

(The most recent version of this handbook, FAA-H-8083-25B, was published in 2016.)

The AIM Pilot-Controller Glossary defines "immediately" as a term used by ATC or pilots when such action compliance was required to avoid an "imminent situation."

The AIM, paragraph 4-4-10, states, in part, the following about adherence to clearance:

- a. When air traffic clearance has been obtained under either visual or instrument flight rules, the pilot-in-command of the aircraft must not deviate from the provisions thereof unless an amended clearance is obtained. When ATC issues a clearance or instruction, pilots are expected to execute its provisions upon receipt. ATC, in certain situations, will include the word "IMMEDIATELY" in a clearance or instruction to impress urgency of an imminent situation and expeditious compliance by the pilot is expected and necessary for safety...
- b. When a heading is assigned or a turn is requested by ATC, pilots are expected to promptly initiate the turn, to complete the turn, and maintain the new heading unless issued additional instructions.

Air Force Manual 11-248, dated January 19, 2011, T-6 Primary Flying, addresses clearing procedures in section 1.16:

1.16. Clearing. Each crewmember is responsible for collision avoidance - regardless of rank, experience, or cockpit position - whether instrument flight rules (IFR) or VFR....Pilots have the responsibility to clear the aircraft in all directions, and although the use of radar monitoring, assigned areas, or ATC separation can assist in ensuring clearance, it does not relieve pilots of the responsibility. The following principles apply to clearing regardless of flight conditions:

1.16.1. Visual detection is the most important factor in clearing for other aircraft.

FAA Guidance to Air Traffic Controllers

FAA Order 7110.65, Air Traffic Control, prescribes ATC procedures and phraseology for use by personnel providing ATC services. Paragraph 2-1-2, "Duty Priority," states, in part, that controllers should "give first priority to separating aircraft and issuing safety alerts as required in this order. Good judgment must be used in prioritizing all other provisions of this order based on the requirements of the situation at hand."

Paragraph 2-1-5, "Expeditious Compliance," states, in part, that controllers should "use the word 'immediately' only when expeditious compliance is required to avoid an imminent situation."

Paragraph 2-1-6, "Safety Alerts," states, in part, the following:

Issue a safety alert to an aircraft if you are aware the aircraft is in a position/altitude that, in your judgment, places it in unsafe proximity to terrain, obstructions, or other aircraft....

Note—

1. The issuance of a safety alert is a first priority...once the controller observes and recognizes a situation of unsafe aircraft proximity to terrain, obstacles, or other aircraft. Conditions, such as workload, traffic volume, the quality/limitations of the radar system, and the available lead time to react are factors in determining whether it is reasonable for the controller to observe and recognize such situations. While a controller cannot see immediately the development of every situation where a safety alert must be issued, the controller must remain vigilant for such situations and issue a safety alert when the situation is recognized....

b. Aircraft Conflict/Mode C Intruder Alert. Immediately issue/initiate an alert to an aircraft if you are aware of another aircraft at an altitude that you believe places them in unsafe proximity. If feasible, offer the pilot an alternate course of action. When an alternate course of action is given, end the transmission with the word "immediately."

Phraseology—

Traffic alert (call sign) (position of aircraft) *advise*
You turn left/right (heading),

and/or

Climb/descend (specific altitude if appropriate)
immediately.

Paragraph 2-1-21, "Traffic Advisories," states the following:

Unless an aircraft is operating within Class A airspace or omission is requested by the pilot, issue traffic advisories to all aircraft (IFR or VFR) on your frequency when, in your judgment, their proximity may

diminish to less than the applicable separation minima. Where no separation minima applies, such as for VFR aircraft outside of Class B/Class C airspace, or a TRSA [terminal radar service area], issue traffic advisories to those aircraft on your frequency when in your judgment their proximity warrants it.

Provide this service as follows:

a. To radar identified aircraft:

1. Azimuth from aircraft in terms of the 12-hour clock, or
2. When rapidly maneuvering aircraft prevent accurate issuance of traffic as in 1 above, specify the direction from an aircraft's position in terms of the eight cardinal compass points (N, NE, E, SE, S, SW, W, and NW). This method must be terminated at the pilot's request.
3. Distance from aircraft in miles.
4. Direction in which traffic is proceeding and/or relative movement of traffic.

Note—

Relative movement includes closing, converging, parallel same direction, opposite direction, diverging, overtaking, crossing left to right, crossing right to left.

5. If known, type of aircraft and altitude.

Phraseology—Traffic, (number) o'clock, or when appropriate,

(direction) (number) miles, (direction)—bound and/or (relative movement),

and if known,

(type of aircraft and altitude).

or

When appropriate,

(type of aircraft and relative position), (number of feet) feet above/below you.

If altitude is unknown,

Altitude Unknown.

Example—

"Traffic, eleven o'clock, one zero miles, southbound, converging, Boeing Seven Twenty Seven, one seven thousand."

"Traffic, twelve o'clock, one five miles, opposite direction, altitude unknown."

"Traffic, ten o'clock, one two miles, southeast bound, one thousand feet below you."

6. When requested by the pilot, issue radar vectors to assist in avoiding the traffic, provided the aircraft to be vectored is within your area of jurisdiction or coordination has been effected with the sector/facility in whose area the aircraft is operating.

7. If unable to provide vector service, inform the pilot.

8. Inform the pilot of the following when traffic you have issued is not reported in sight:

(a) The traffic is no factor.

(b) The traffic is no longer depicted on radar.

Phraseology—

Traffic no factor/no longer observed,

or

(number) *o'clock traffic no factor/no longer observed,*

or

(direction) *traffic no factor/no longer observed.*

b. To aircraft that are not radar identified:

1. Distance and direction from fix.
2. Direction in which traffic is proceeding.
3. If known, type of aircraft and altitude.
4. ETA over the fix the aircraft is approaching, if appropriate.

Phraseology—

Traffic, (number) miles/minutes (direction) of (airport or fix), (direction)—bound,

and if known,

(type of aircraft and altitude),

estimated (fix) (time),

or

Traffic, numerous aircraft vicinity (location).

If altitude is unknown,

Altitude Unknown.

Example—

"Traffic, one zero miles east of Forsythe V-O-R, Southbound, M-D Eighty, descending to one six thousand."

"Traffic, reported one zero miles west of Downey V-O-R, northbound, Apache, altitude unknown, estimated Joliet V-O-R one three one five."

"Traffic, eight minutes west of Chicago Heights V-O-R, westbound, Mooney, eight thousand, estimated Joliet V-O-R two zero three five."

"Traffic, numerous aircraft, vicinity of Delia airport."

c. For aircraft displaying Mode C, not radar identified, issue indicated altitude.

Example—

"Traffic, one o'clock, six miles, eastbound, altitude indicates six thousand five hundred."

The See-and-Avoid Concept

The FAA issued AC 90-48C, "Pilots' Role in Collision Avoidance," in 1983 to alert all pilots "...to the potential hazards of midair collisions and near midair collision [NMAC], and to emphasize those basic problem areas related to the human causal factors where improvements in pilot education, operating practices, procedures, and improved scanning techniques are needed to reduce midair conflicts." (This version of the AC was in place at the time of the accident; an updated version, AC 90-48D, was issued in April 2016 and is discussed further below.)

AC 90-48C stated that each person operating an aircraft, regardless of whether the operation was conducted under IFR or VFR, shall maintain a vigilant lookout for other aircraft at all times. Regarding visual scanning, the AC specifically stated that "Pilots should remain constantly alert to all traffic movement within their field of vision, as well as periodically scanning the entire visual field outside of their aircraft to ensure detection of conflicting traffic" (emphasis in the original). AC 90-48C also described several specific methods that pilots could use to visually acquire other traffic.

AC 90-48C also discussed the use of ATC services:

One of the major factors contributing to the likelihood of NMAC incidents in terminal areas that have an operating air traffic control (ATC) system has been the mix of known arriving and departing aircraft with unknown traffic. The known aircraft are generally in radio contact with the controlling facility (local, approach, or departure control) and the other aircraft are neither in two-way radio contact nor identified by ATC at the time of the NMAC. (emphasis in the original)

The AC recommended that pilots use ATC traffic advisory services but stressed that those services do not lessen the pilot's obligation to see and avoid other traffic.

Finally, the AC provided data on the time required for a pilot to recognize an approaching aircraft and execute an evasive maneuver. The total time to identify an approaching aircraft, recognize a collision course, decide on action, execute the control movement, and allow the aircraft to respond was estimated to be around 12.5 seconds.

In 1991, the Australian Transport Safety Bureau (ATSB) published a research report titled Limitations of the See-and-Avoid Principle. The report discusses the role of the see-and-avoid concept in preventing collisions and some of its inherent limitations:

Cockpit workload and other factors reduce the time that pilots spend in traffic scans. However, even when pilots are looking out, there is no guarantee that other aircraft will be sighted. Most cockpit windscreen configurations severely limit the view available to the pilot. The available view is frequently interrupted by obstructions such as window-posts which totally obscure some parts of the view and make other areas visible to only one eye....Visual scanning involves moving the eyes in order to bring successive areas of the visual field onto the small area of sharp vision in the centre of the eye. The process is frequently unsystematic and may leave large areas of the field of view unsearched....The physical limitations of the human eye are such that even the most careful search does not guarantee that

traffic will be sighted....An object which is smaller than the eye's acuity threshold is unlikely to be detected and even less likely to be identified as an approaching aircraft....The human visual system is better at detecting moving targets than stationary targets, yet in most cases, an aircraft on a collision course appears as a stationary target in the pilot's visual field. The contrast between an aircraft and its background can be significantly reduced by atmospheric effects, even in conditions of good visibility. An approaching aircraft, in many cases, presents a very small visual angle until a short time before impact. In addition, complex backgrounds such as ground features or clouds hamper the identification of aircraft via a visual effect known as 'contour interaction'. This occurs when background contours interact with the form of the aircraft, producing a less distinct image. Even when an approaching aircraft has been sighted, there is no guarantee that evasive action will be successful.

The ATSB report also discusses the value of alerted versus unalerted searches for traffic:

A traffic search in the absence of traffic information is less likely to be successful than a search where traffic information has been provided because knowing where to look greatly increases the chance of sighting the traffic (Edwards and Harris 1972). Field trials conducted by John Andrews found that in the absence of a traffic alert, the probability of a pilot sighting a threat aircraft is generally low until a short time before impact. Traffic alerts were found to increase search effectiveness by a factor of eight. A traffic alert from ATS or from a radio listening watch is likely to be similarly effective (Andrews 1977, Andrews 1984, Andrews 1987).

The ATSB report concludes, in part, that "The see-and-avoid principle in the absence of traffic alerts is subject to serious limitations....Unalerted see-and-avoid has a limited place as a last resort means of traffic separation at low closing speeds but is not sufficiently reliable to warrant a greater role in the air traffic system."

Cockpit Display of Traffic Information

In April 2016, the FAA published an update to "Pilots' Role in Collision Avoidance" (AC 90 48D), which highlights aircraft systems and technologies available to improve safety and aid in collision avoidance. Among those technologies, the recommended safety equipment includes TAS, TCAS (I and II), and ADS-B with display capability. The updated AC also discusses the information provided by each of these systems and stresses that they are intended as a supplement to, and not replacement for, the visual acquisition and avoidance of other aircraft.

Regarding the use of ADS-B as a tool to aid in a pilot's situational awareness, the AC states, in part, the following:

ADS-B is a system for air traffic surveillance. The FAA has mandated ADS-B Out by 2020 on all aircraft operating in current Mode C airspace (around Class B and C airspace and above 10,000 feet). With ADS-B, each aircraft broadcasts its own Global Positioning System (GPS) position along with other information like heading, ground track, groundspeed, and altitude (ADS-B Out). To see other aircraft, you must be equipped with ADS-B In to process the data signals.

The AC describes how other systems that actively interrogate other aircraft would continue to be useful beyond the FAA-mandated ADS-B Out requirement in 2020:

Active Traffic Systems. Active traffic systems (including TAS and TCAS) use Mode A, C, or S transponder interrogations to determine aircraft bearing and distance. Altitude is determined by reported Mode C altitude. After 2020, aircraft will be required to broadcast ADS-B Out and this data can be interpreted by aircraft with ADS-B In, but aircraft will still be required to have a Mode C or S transponder in airspace where it is currently required; thus, active traffic systems will continue to function. Most TAS systems will have ADS-B In capability available as an upgrade so these systems can interpret signals from either source.

Active Traffic Systems in an ADS-B Environment. Active traffic systems are valuable for three reasons in an ADS-B environment. First, even after January 1, 2020, not all aircraft will have ADS-B Out, particularly in airspace which does not require it. Thus, without an active traffic system, those unequipped aircraft would not display on a cockpit traffic display even if you had ADS-B In. Second, an active traffic system will display all aircraft independent of the type of ADS-B Out, since all aircraft will still be required to have a Mode C or Mode S transponder. Third, ADS-B is dependent on GPS signals, so during periods of poor satellite geometry or solar storms, GPS position and thus ADS-B could be disrupted and less reliable, meaning an active traffic system can act as a backup to ADS-B in the cockpit.

In 1977, the Massachusetts Institute of Technology published a report for the FAA, titled Air to Air Visual Acquisition Performance with Pilot Warning Instruments (PWI), which describes how PWI could be used to aid pilots in the visual acquisition task. These instruments would generally use some electronic means to detect and then present pilots with information about particular threats, focusing their attention to where it was most needed:

The primary intent of PWI is to improve the search performance of the pilot. The PWI alarm ensures that scanning will be given high priority when it is most critical and by directing the pilot's search to a particular sector, the area to be scanned is greatly reduced. Another effect discovered in the IPC [Intermittent Positive Control]/PWI flight tests is the tendency of PWI to reduce the effect of airframe obstruction. Not only do pilots shift their positions within the cockpit in an effort to scan a threat sector, but many pilots alter the aircraft attitude in order to achieve an unobstructed view in the threat direction. Thus, PWI favorably affects the first two elements of acquisition (search and field of view). It does not alter detectability or speed of approach in any direct way.

Research into pilots' performance in the visual acquisition task conducted in support of the report found that "Unaided visual acquisition is effective as a means of separation assurance only for lower values of crossing angles (relative heading). At higher values of crossing angle the increased closure speeds and decreased visible areas reduce performance considerably."

In our report regarding a midair collision over the Hudson River (Midair Collision Over Hudson River, Piper PA-32R-300, N71MC, and Eurocopter AS350BA, N401LH, Near Hoboken, New Jersey, August 8, 2009, AAR-10/05), the NTSB stated, in part, the following;

There are inherent limitations associated with the see-and-avoid concept as the primary method for aircraft separation. These limitations include a pilot's ability to perform systematic scans, competing operational task demands, environmental factors, and blind spots associated with an aircraft's structure.

Traffic advisory systems can provide pilots with additional information to facilitate pilot efforts to maintain awareness of and visual contact with nearby aircraft to reduce the likelihood of a collision.

Most traffic advisory systems, including TIS [traffic information service], have visual displays of nearby traffic that show an aircraft's position or distance, direction of travel, and relative altitude and indicate whether the aircraft is climbing or descending. The NTSB recognizes that incorporating a visual traffic display into a pilot's scan could increase workload, but any increase in workload would be offset by the safety benefits resulting from the augmented awareness of other aircraft operating in the area, as displayed by the traffic system. However, these safety benefits are not a substitute for the see-and-avoid concept. In fact, Garmin guidance stated that TIS does not relieve pilots of their responsibility to see and avoid other aircraft. Thus, pilots are responsible for paying attention to the position of other aircraft for collision avoidance and not relying solely on a traffic advisory system for aircraft position information.

Administrative Information

Investigator In Charge (IIC):	Diaz, Dennis
Additional Participating Persons:	James Dangerfield; FAA/FSDO; West Columbia, SC Paul E Yoos; Textron Aviation; Wichita, KS Randolph Rushworth; USAF; Albuquerque, NM James Estes; FAA/AJI; Washington, DC Eric Stormfels; NATCA; Washington, DC Marcus Tibbs; Lockheed Martin Aeronautics; Fort Worth, TX Kenneth Worrell; Lockheed Martin Aeronautics; Fort Worth, TX Robert Koehler; Lockheed Martin Aeronautics; Fort Worth, TX David Vandercook; Lockheed Martin Aeronautics; Fort Worth, TX Dennis Lasater; Lockheed Martin Aeronautics; Fort Worth, TX Jacob Hannusch; Lockheed Martin Aeronautics; Fort Worth, TX Stephen Guest; Lockheed Martin Aeronautics; Fort Worth, TX Kyle Ringgenberg; Lockheed Martin Aeronautics; Fort Worth, TX
Original Publish Date:	November 15, 2016
Last Revision Date:	July 8, 2024
Investigation Class:	Class 2
Note:	The NTSB traveled to the scene of this accident.
Investigation Docket:	https://data.nts.gov/Docket?ProjectID=91508

The National Transportation Safety Board (NTSB) is an independent federal agency charged by Congress with investigating every civil aviation accident in the United States and significant events in other modes of transportation—railroad, transit, highway, marine, pipeline, and commercial space. We determine the probable causes of the accidents and events we investigate, and issue safety recommendations aimed at preventing future occurrences. In addition, we conduct transportation safety research studies and offer information and other assistance to family members and survivors for each accident or event we investigate. We also serve as the appellate authority for enforcement actions involving aviation and mariner certificates issued by the Federal Aviation Administration (FAA) and US Coast Guard, and we adjudicate appeals of civil penalty actions taken by the FAA.

The NTSB does not assign fault or blame for an accident or incident; rather, as specified by NTSB regulation, “accident/incident investigations are fact-finding proceedings with no formal issues and no adverse parties ... and are not conducted for the purpose of determining the rights or liabilities of any person” (Title 49 *Code of Federal Regulations* section 831.4). Assignment of fault or legal liability is not relevant to the NTSB’s statutory mission to improve transportation safety by investigating accidents and incidents and issuing safety recommendations. In addition, statutory language prohibits the admission into evidence or use of any part of an NTSB report related to an accident in a civil action for damages resulting from a matter mentioned in the report (Title 49 *United States Code* section 1154(b)). A factual report that may be admissible under 49 *United States Code* section 1154(b) is available [here](#).