



AVIATION



HIGHWAY



MARINE



RAILROAD



PIPELINE

Aviation Investigation Final Report

Location:	San Diego, California	Accident Number:	WPR15MA243
Date & Time:	August 16, 2015, 11:03 Local	Registration:	N1285U
Aircraft:	Cessna 172M	Aircraft Damage:	Destroyed
Defining Event:	Midair collision	Injuries:	1 Fatal
Flight Conducted Under:	Part 91: General aviation - Personal		

Analysis

The Cessna 172 (N1285U) was conducting touch-and-go landings at Brown Field Municipal Airport (SDM), San Diego, California, and the experimental North American Rockwell NA265-60SC Sabreliner (N442RM, call sign Eagle1) was returning to SDM from a mission flight. SDM has two parallel runways, 8R/26L and 8L/26R; it is common in west operations for controllers to use a right traffic pattern for both runways 26R and 26L due to the proximity of Tijuana Airport, Tijuana, Mexico, to the south of SDM. On the morning of the accident, the air traffic control tower (ATCT) at SDM had both control positions (local and ground control) in the tower combined at the local control position, which was staffed by a local controller (LC)/controller-in-charge, who was conducting on-the-job training with a developmental controller (LC trainee). The LC trainee was transmitting control instructions for all operations; however, the LC was monitoring the LC trainee's actions and was responsible for all activity at that position.

About 13 minutes before the accident, the N1285U pilot contacted the ATCT and requested touch-and-go landings in the visual flight rules (VFR) traffic pattern. About that time, another Cessna 172 (N6ZP) and a helicopter (N8360R) were conducting operations in the VFR traffic pattern, and a Cessna 206 Stationair (N5058U) was inbound for landing. Over the next 5 minutes, traffic increased, with two additional aircraft inbound for landing. (Figure 1 in the factual report for this accident shows the aircraft in the SDM traffic pattern about 8 minutes before the accident.)

The LC trainee cleared the N1285U pilot for a touch-and-go on runway 26R; the pilot acknowledged the clearance and then advised the LC trainee that he was going to go around. The LC trainee advised the N1285U pilot to expect runway 26L on the next approach. At that time, three aircraft were using runway 26R (Global Express [N18WZ] was inbound for landing, N6ZP was on a right base for a touch-and-go, and a Cessna Citation [XALVV] was on short final) and three aircraft were using runway 26L (N1285U was turning right downwind for the touch-and-go, a Skybolt [N81962] was on a left downwind for landing, and N8360R was conducting a touch-and-go landing). After N1285U completed the touch-and-go on runway 26L, the pilot entered a right downwind for runway 26R.

Meanwhile, Eagle1 was 9 miles west of the airport and requested a full-stop landing; the LC trainee instructed the Eagle1 flight crew to enter a right downwind for runway 26R at or above an altitude of 2,000 ft mean sea level. At this time, about 3 minutes before the accident, the qualified LC terminated the LC trainee's training and took over control of radio communications. From this time until the collision occurred, the LC was controlling nine aircraft. (Figure 2 and Figure 4 in the factual report for this accident show the total number of aircraft under ATCT control shortly before the accident.)

During the next 2 minutes, the LC made several errors. For example, after N6ZP completed a touch-and-go on runway 26R, the pilot requested a right downwind departure from the area, which the LC initially failed to acknowledge. The LC also instructed the N5058U pilot, who had been holding short of runway 26L, that he was cleared for takeoff from runway 26R. Both errors were corrected. In addition, the LC instructed the helicopter pilot to "listen up. turn crosswind" before correcting the instruction 4 seconds later to "turn base." (Figure 2 in the factual report for this accident shows the aircraft in the traffic pattern about 2 minutes before the accident.)

About 1 minute before the collision, the Eagle1 flight crew reported on downwind midfield and stated that they had traffic to the left and right in sight. At that time, N1285U was to Eagle1's right, between Eagle1 and the tower, and established on a right downwind about 500 ft below Eagle1's position. N6ZP was about 1 mile forward and to the left of Eagle1, heading northeast and departing the area. Mistakenly identifying the Cessna to the right of Eagle1 as N6ZP, the LC instructed the N6ZP pilot to make a right 360° turn to rejoin the downwind when, in fact, N1285U was the airplane to the right of Eagle1. (The LC stated in a postaccident interview that he thought the turn would resolve the conflict with Eagle1 and would help the Cessna avoid Eagle1's wake turbulence.) The N6ZP pilot acknowledged the LC's instruction and began turning; N1285U continued its approach to runway 26R.

However, the LC never visually confirmed that the Cessna to Eagle1's right (N1285U) was making the 360° turn. Ten seconds later, the LC instructed the Eagle1 flight crew to turn base and land on runway 26R, which put the accident airplanes on a collision course. The LC looked to ensure that Eagle1 was turning as instructed and noticed that the Cessna on the right downwind (which he still mistakenly identified as N6ZP) had not begun the 360° turn that he had issued. The LC called the N6ZP pilot, and the pilot responded that he was turning. In the first communication between the LC and the N1285U pilot (and the first between the controllers in the ATCT and that airplane's pilot in almost 6 minutes), the LC transmitted the call sign of N1285U, which the pilot acknowledged. N1285U and Eagle1 collided as the LC tried to verify N1285U's position.

A postaccident examination of both airplanes did not reveal any mechanical anomalies that would have prevented the airplanes from maneuvering to avoid an impact.

Local Controller Actions

In a postaccident interview, the LC stated that his personal limit for handling aircraft was four aircraft on runway 26R plus three aircraft on runway 26L (for a total of seven). From the time the LC took over local control communications from the LC trainee (3 minutes before the accident) until the time of the collision, the LC was in control of nine aircraft. Thus, the LC had exceeded his own stated workload limit. Research indicates that the cognitive effects of increasing workload may include memory deficits; distraction; narrowing of attention; decreased situational awareness; and increased errors, such as readback errors or giving instructions to the wrong aircraft. (Mica Endsley and Mark Rodgers's 1997

report, *Distribution of Attention, Situation Awareness, and Workload in a Passive Air Traffic Control Task: Implications for Operational Errors and Automation* [FAA Report No. DOT/FAA/AM-97/13], details the cognitive effects of increasing workload.) To resolve the increasing workload, the LC had two options. He could have directed traffic away from SDM or split the local control/ground control positions, but he did neither. The LC trainee was qualified to work the ground control position, and the SDM ATCT had three controllers in the facility, which was the normal staffing schedule for that day and time.

As a result of the high workload, the LC made several errors after taking over the position from the LC trainee, including not responding promptly to a departure request from the N6ZP pilot and incorrectly instructing a helicopter pilot to turn to crosswind before correcting the instruction to turn base. The LC also did not provide traffic and/or sequence information with the instructions for the N6ZP pilot to turn 360° right. If the LC had done so, the N6ZP pilot might have reminded the controller that he was departing the airspace or requested clarification per 14 *Code of Federal Regulations (CFR)* 91.123(a), "Compliance with ATC [Air Traffic Control] Clearances and Instructions." In addition, if the Eagle1 flight crew had heard their aircraft called as traffic to another aircraft, it may have helped their visual search or prompted them to seek more information about the location of the conflicting traffic. The LC's stress amid the high workload was evidenced in his "listen up. turn crosswind" instruction to the helicopter pilot, after which the Eagle1 cockpit voice recorder (CVR) recorded the pilot comment, "wowwww. he's like panicking" (with an emphasis on "panicking").

Most importantly, the LC misidentified N1285U as N6ZP and did not ensure that the Cessna to the right of Eagle1 was performing the 360° turn before issuing the turn instruction to Eagle1. Although the N6ZP pilot had already requested a departure from the area and the LC had approved the departure request, the LC still believed that N6ZP was to the right of Eagle1, which indicates that the LC lacked a full and accurate mental model of the situation once he took over communications from the LC trainee. The LC trainee stated in a postaccident interview that when the Cessna on the right did not start the right turn, he suggested to the LC that the intended aircraft may have been N1285U. The high workload due to the increased traffic likely contributed to the LC's incomplete situational awareness.

In a postaccident interview, the LC reported that, at the time that he took over for the LC trainee, he had four issues to resolve, one of which was the potential conflict between Eagle1 and the Cessna on the right. Thus, he was aware of the potential conflict between two aircraft, even though he did not have the accurate mental picture of which Cessna was which. The LC explained that the acknowledgement from the N6ZP pilot of the right 360° turn to rejoin the downwind indicated to him that the intended Cessna pilot to Eagle1's right had received and acknowledged his instructions. Had he looked up to ensure that the control instructions that he provided to the Cessna on the right were being performed, he would have noticed that the Cessna to the right of Eagle1 was not turning and likely would not have issued the conflicting turn instruction to Eagle1.

Further, Federal Aviation Administration (FAA) Order 7110.65, paragraph 2-1-6, "Safety Alerts," states, in part, that a controller should "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..." About 14 seconds elapsed between the LC's base turn instruction and landing clearance for Eagle1 and his call to the N6ZP pilot to ask about the right 360° turn instruction. When the LC saw that the airplanes were in unsafe proximity to each other, his priority should have been to separate the aircraft by issuing a safety alert to the Eagle1 flight crew (such as "TRAFFIC ALERT, Eagle1, to your

right and below at pattern altitude, advise you climb immediately"). However, instead of issuing a safety alert to the Eagle1 flight crew, he separately called each Cessna pilot to verify their call signs and positions, which demonstrated narrowing of attention, another indication of the LC's stress due to high workload. If the LC had issued a safety alert to the Eagle1 flight crew as soon as he looked up after clearing Eagle1 to land and noticed that the Cessna to the right of Eagle1 was not turning, the Eagle1 pilots may have been able to take action to avoid N1285U. After the accident, on August 26, 2015, the SDM ATCT issued a Corrective Action Plan regarding inconsistencies in how controllers were issuing traffic advisories and safety alerts. The plan required controllers to review FAA Order 7110.65V, *Air Traffic Control*, paragraphs 2-1-6 and 2-1-21, as refresher training before working an operational position.

See-and-Avoid Concept

According to 14 *CFR* 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." 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 instrument flight rules 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.

A review of the ATCT and Eagle1 CVR transcripts revealed that during the entire time that the Eagle1 flight crew was on the ATCT local control frequency, there were no communications to or from N1285U. According to the CVR transcript, the Eagle1 pilots were aware of other traffic in the area and were actively looking for it; they had multiple airplanes in sight while on the downwind leg, and the pilot stated "I see the shadow but I don't see him" shortly before the accident. (Review of available data indicated that it was most likely the shadow of N1285U.)

Aircraft Performance and Cockpit Visibility Study

Our aircraft performance and cockpit visibility study determined that once Eagle1 began the turn to base leg, Eagle1 would have been largely obscured from the N1285U pilot's field of view but that N1285U should have remained in the Eagle1 pilots' field of view until about 4 seconds before the collision. (Figures 8a and 8b in the factual report for this accident show the simulated cockpit visibility from the Eagle1 copilot's seat and the N1285U pilot's seat at 1102:34, respectively.) Although the Eagle1 copilot would have had a better viewing position (in the right seat) to detect N1285U than the pilot, he was the pilot flying; thus, his attention would have been divided among multiple tasks, including configuring, operating, and maneuvering the airplane for approach and landing, as well as scanning for traffic. (Throughout Eagle1's CVR recording, the pilot, seated in the left seat, was communicating on the radio and responding to checklists, consistent with that pilot acting as the pilot monitoring and the copilot,

seated in the right seat, acting as the pilot flying.) N1285U's lack of relative motion in the Eagle1 pilots' field of view, combined with the fact that N1285U was below their horizon and, therefore, against the visual clutter of the background terrain, significantly decreased N1285U's visual conspicuity to the Eagle1 pilots.

It is likely that, as N1285U neared the end of the downwind leg (after Eagle1 overtook N1285U from behind and to the left), the pilot was anticipating his turn to the base leg and that his primary external visual scan was to the right, toward the airport, instead of to the left where Eagle1 was. Although the pilot may have had some cues of Eagle1's relative positioning in the pattern based on his monitoring of the ATCT communications, the challenge remained of detecting the airplane visually while maneuvering in the pattern.

Cockpit Display of Traffic Information

Although the N1285U and Eagle1 pilots were responsible for seeing and avoiding the other aircraft in the traffic pattern, our aircraft performance and cockpit visibility study revealed that their fields of view were limited and partially obscured at times. Research indicates that any mechanism to augment and focus a pilot's visual search 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. The accident airplanes were not equipped with these types of systems, but 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.)

While Eagle1 remained obscured from the N1285U pilot's field of view during Eagle1's downwind-to-base turn, N1285U remained in the Eagle1 (right seat) copilot's field of view for the majority of the 3 minutes preceding the accident. Even though both Eagle1 pilots were aware of and actively looking for traffic in the pattern, they still failed to see and avoid colliding with N1285U, which underscores the shortcomings in the see-and-avoid concept. An in-cockpit traffic display would have shown the Eagle1 pilots all of the traffic at the airport about the time of their initial call to the ATCT, and, about 2 minutes later, the Eagle1 pilots would have received an aural alert; the display would have shown N1285U's target change from a cyan color to a yellow color positioned between Eagle1 and the airport. About 1 1/2 minutes later, the Eagle1 pilots would have received another aural alert. The N1285U pilot would also have received an aural alert several seconds before impact, which may not have given him enough time to take evasive action. While most systems are limited to aiding pilots in their visual acquisition of a target and cannot provide resolution advisories (specific maneuvering instructions intended to avoid the collision), a cockpit indication of traffic would likely have heightened the pilots' situational awareness and possibly alerted them of the need to change their flightpaths to resolve the conflict.

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 July 7, 2015, near Moncks Corner, South Carolina; 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.)

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be:

The local controller's (LC) failure to properly identify the aircraft in the pattern and to ensure control instructions provided to the intended Cessna on downwind were being performed before turning Eagle1 into its path for landing. Contributing to the LC's actions was his incomplete situational awareness when he took over communications from the LC trainee due to the high workload at the time of the accident. Contributing to the accident were the inherent limitations of the see-and-avoid concept, resulting in the inability of the pilots involved to take evasive action in time to avert the collision.

Findings

Personnel issues	Attention - ATC personnel
Personnel issues	Accuracy of communication - ATC personnel
Personnel issues	Situational awareness - ATC personnel
Personnel issues	Task scheduling - ATC personnel
Personnel issues	Monitoring other aircraft - Not specified

Factual Information

History of Flight

**Approach-VFR pattern
downwind**

Midair collision (Defining event)

This report was modified on October 31, 2016. Please see the docket for this accident to view the original report.

On August 16, 2015, about 1103 Pacific daylight time, a Cessna 172M, N1285U, and an experimental North American Rockwell NA265-60SC Sabreliner, N442RM (call sign Eagle1), collided in midair about 1 mile northeast of Brown Field Municipal Airport (SDM), San Diego, California. The pilot (and sole occupant) of N1285U and the two pilots and two mission specialists aboard Eagle1 died; both airplanes were destroyed. N1285U was registered to a private individual and operated by Plus One Flyers under the provisions of 14 Code of Federal Regulations (CFR) Part 91 as a personal flight. Eagle1 was registered to and operated by BAE Systems Technology Solutions & Services, Inc., for the US Department of Defense as a public aircraft in support of the US Navy. No flight plan was filed for N1285U, which originated from Montgomery-Gibbs Executive Airport, San Diego, California. A mission flight plan was filed for Eagle1, which originated from SDM about 0830 and was returning to SDM. Visual meteorological conditions prevailed at the time of the accident.

On the morning of the accident, the SDM airport traffic control tower (ATCT) had all control positions (local and ground control) in the tower combined to the local control position. The position was staffed by a qualified local controller (LC)/controller-in-charge (CIC) who was conducting on-the-job training with a developmental controller (LC trainee) on the local control position. The LC trainee was transmitting control instructions for all operations; however, the qualified LC was closely monitoring the LC trainee's actions and was responsible for all activity at that position.

According to air traffic control (ATC) radar and voice communications data, the pilot of N1285U contacted the SDM ATCT at 1049:44 and requested touch-and-go maneuvers in the visual flight rules (VFR) traffic pattern. N1285U was inbound about 6 miles to the northeast of SDM, at an indicated altitude of 2,600 ft. About that time, another Cessna 172 (N6ZP) and a helicopter (N8360R) were conducting operations in the VFR traffic pattern, and a Cessna 206 Stationair (N5058U) was inbound for landing after carrying parachutists to a local drop zone about 5 nautical miles (nm) east of the field.

Between about 1049 and 1054, N6ZP and the helicopter continued to conduct approaches, N5058U landed on runway 26L, a Skybolt (N81962) reported west of SDM for landing on runway 26L, and a Cessna Citation (XALVV) reported straight in for landing on runway 26R. At 1052:57, the LC trainee cleared the pilot of N1285U for a touch-and-go on runway 26R, which the pilot acknowledged. At 1054:46, when N1285U was on final approach of the first approach to runway 26R, the pilot advised the LC trainee that he was going to go around. The LC trainee acknowledged the transmission and instructed the pilot to follow "a Cessna" (N6ZP) on the right downwind.

At 1056:31, the LC trainee advised the pilot of N1285U to expect runway 26L on the next approach, which the pilot acknowledged. At that time, three aircraft were using runway 26R (Global Express [N18WZ] was inbound for landing, N6ZP was on a right base for a touch-and-go, and XALVV was on short final) and three aircraft were using runway 26L (N1285U was turning right downwind for the touch-and-go, N81962 was on a left downwind for landing, and N8360R was conducting a touch-and-go operation). Figure 1 shows the aircraft in the SDM traffic pattern about 8 minutes before the accident.



Figure 1. Aircraft in the SDM traffic pattern about 8 minutes before the accident.

At 1057:22, the LC trainee cleared the pilot of N1285U for a touch-and-go on runway 26L, and at 1057:27, the pilot acknowledged the clearance. At 1058:22, the LC trainee cleared the pilot of N6ZP for a touch-and-go on runway 26L. At 1058:29, the pilot of N6ZP stated, "...ah two six right cleared touch and go." After the pilot of N1285U completed the touch-and-go on runway 26L, the pilot turned the airplane right, crossing through the departure corridor of runway 26R, and entered a right downwind for runway 26R.

At 1059:04, when Eagle1 was 9 miles west of SDM, the flight crew contacted the SDM ATCT and requested a full-stop landing. Throughout Eagle1's cockpit voice recorder (CVR) recording, the pilot, seated in the left seat, was communicating on the radio and responding to checklists, consistent with that pilot acting as the pilot monitoring and the copilot, seated in the right seat, acting as the pilot flying. The LC trainee instructed the Eagle1 flight crew to enter a right downwind for runway 26R at or above an altitude of 2,000 ft mean sea level (msl).

At 1059:18, the pilot of N5058U reported holding short of runway 26L on taxiway C. (N5058U had landed on runway 26L at 1052:30 and was returning to runway 26L for takeoff.) The LC trainee mistakenly advised the pilot of N5058U to hold short of runway 26R. The pilot of N5058U clarified that he was holding short of 26L, and, at 1059:31, the LC trainee acknowledged the transmission. That was the last transmission from the LC trainee. At 1059:33, the qualified LC terminated the LC trainee's training and took over control of communications due to increased traffic. The LC trainee signed off the position but remained in the tower to observe operations. From this time until the collision occurred (about 1103), the LC was controlling nine aircraft.

During the next 2 minutes, the LC made several errors that were either corrected by him or by the pilots under his control. At 1059:44, after the pilot of N6ZP completed a touch-and-go on runway 26R, he requested a right downwind departure from the area. The LC did not respond. At 1100:23, the LC instructed, "stationair five eight uniform two six right cleared for I'm sorry two six left cleared for takeoff." At 1100:29, the pilot of N5058U stated, "uh I'm sorry was that for five eight uniform?" The LC then cleared the pilot of N5058U for takeoff from runway 26L. At 1100:36, the LC transmitted, "helicopter six zero romeo there is a ces ah cen ah correction stationair just ahead they are going to the right runway base leg for two six left." At 1100:46, the pilot of N6ZP repeated his request for departure; the LC then approved N6ZP's departure request, and N6ZP departed the traffic pattern in a northeasterly direction. At 1100:53, the LC instructed the helicopter pilot, "helicopter six zero romeo listen up turn crosswind" before correcting the instruction 4 seconds later to "turn base." At 1101:15, the Eagle1 CVR recorded the copilot state, "got one on the runway," and at 1101:19, the Eagle1 CVR recorded the pilot comment, "wowwww. he's like panicking" (with an emphasis on panicking). Figure 2 shows the aircraft in the SDM traffic pattern from about 1101 until the time of the accident.

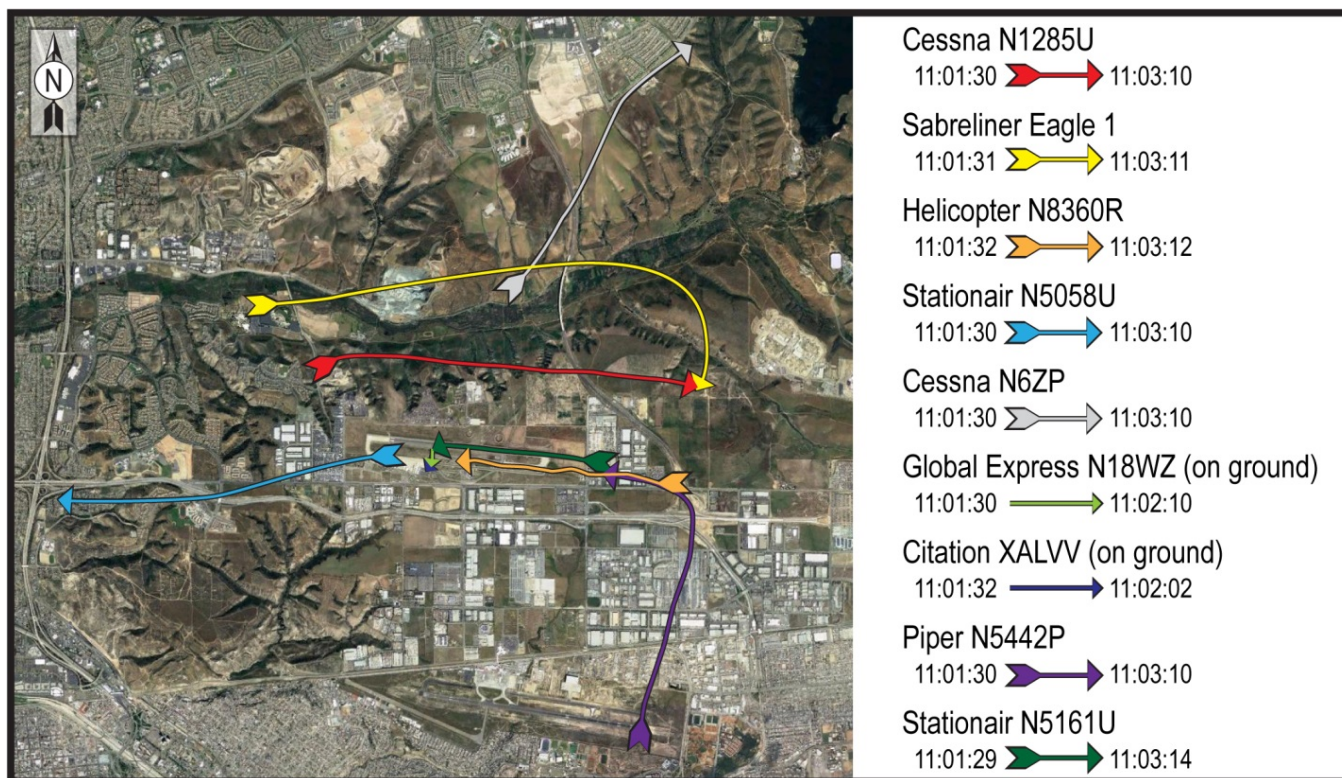


Figure 2. Aircraft in the SDM traffic pattern from about 1101 until the time of the accident.

At 1101:49, the Eagle1 CVR recorded one of the mission specialists seated outside the cockpit ask "see him right there?" At 1102:14, while on the right downwind leg (and, according to radar data, while overtaking N1285U from behind and to the left) and abeam the tower, the Eagle1 flight crew reported to the ATCT that they had traffic in sight to the left and the right of their position. Radar data indicated that N6ZP was to the left of Eagle1 and heading to the northeast, and N1285U was between Eagle1 and SDM, on a closer-in right downwind leg.

At 1102:32, the LC instructed the pilot of N6ZP, which he thought was the Cessna on right downwind, to make a right 360° turn over the airport and rejoin the downwind. Despite the fact that, at that time, N6ZP was 2.3 nm northeast of the airport and was departing the area, the pilot of N6ZP acknowledged the instruction and initiated a right turn. At the same time, Eagle1's CVR recorded the pilot asking, "you still got the guy on the right side?"

At 1102:42, the LC instructed the Eagle1 flight crew to turn base and cleared the flight to land on runway 26R. The LC stated in the postaccident interview that after he cleared the Eagle1 flight crew to land, he looked up to ensure that Eagle1 was turning base and noticed that the Cessna on downwind (which he still thought was N6ZP) was continuing on its downwind track and had not begun the turn that

he had issued. At 1102:56, the LC contacted the pilot of N6ZP, and the N6ZP pilot replied by stating that he was turning. At 1102:59, Eagle1's CVR recorded the pilot comment "I see the shadow but I don't see him."

At 1103:04, the LC transmitted "November eight five uniform"; this was the first ATC transmission with N1285U in almost 6 minutes and the first communication between the LC and N1285U. At 1103:07, the pilot of N1285U acknowledged the transmission, "eight five uniform." At 1103:08, the LC asked the pilot of N1285U if he was still on the right downwind leg. The pilot of N1285U did not respond. The LC and the LC trainee then witnessed Eagle1 and N1285U collide.

Two witnesses located on the ramp at SDM saw the two airplanes flying eastbound, to the north of SDM. The witnesses turned away momentarily, and as they turned back, they saw an explosion, followed by airplane fragments falling to the ground. Another witness located about 2 miles east-northeast of SDM saw both airplanes at the same altitude, on intersecting flightpaths. That witness reported that the smaller airplane was flying away from the airport and that the larger airplane was flying toward the airport and descending. He noted that neither airplane appeared to make any corrective action before the collision and stated that after the collision, the smaller airplane broke apart, while the larger airplane lost a wing, nosed down, and impacted the ground.

The LC stated in a postaccident interview that the traffic level was "light and not complex" at the beginning of the training session. He stated that he noticed the traffic volume and complexity became "moderate" when the LC trainee was under instruction, which prompted the LC to terminate training and take over communications. He reported that, at that time, he had four issues to resolve, one of which was the potential conflict between Eagle1 and the Cessna on the right. He indicated that he saw Eagle1 on a midfield right downwind leg when the pilot of Eagle1 reported that he was "abeam and had the traffic to the left and right in sight." The LC stated that, at that time, Eagle1 was flanked by two Cessnas. Although the Cessna on the right of Eagle1 was N1285U, the LC believed that the Cessna on the close-in right downwind was N6ZP; therefore, he instructed the pilot of N6ZP to make a right 360° turn to rejoin the midfield downwind. He stated that he felt the turn would resolve the conflict with Eagle1 and that the right turn would help the Cessna avoid Eagle1's wake turbulence. When the pilot of N6ZP acknowledged the turn, the LC believed that the pilot of the Cessna to the right of Eagle1 had received the instructions and that the potential conflict with Eagle1 would be resolved. The LC then instructed Eagle1 to turn base and cleared the flight crew to land on runway 26R.

The LC stated that after he cleared the Eagle1 flight crew to land, he looked up to ensure that Eagle1 was turning as instructed. When the LC noticed that the Cessna to the right of Eagle1 had not started the right 360° turn, he began to query the pilot of N6ZP and then the pilot of N1285U. At that point, he witnessed the collision.

The LC also indicated in the postaccident interview that controllers have personal limits about how many airplanes they could handle and that he could handle four aircraft on runway 26R and three aircraft on runway 26L. When the LC was asked what caused him to realize that the Cessna was N1285U and not N6ZP, he said it dawned on him that he had a right downwind departure, and through the process of elimination, it could not have been anyone else. The LC trainee stated in a postaccident interview that when the Cessna on the right did not start the right turn, he suggested to the LC that the intended aircraft may have been N1285U. The LC indicated that, in retrospect, he should have issued a

traffic alert; however, the moment he realized that Eagle1 was turning into N1285U, it was too late to help. Figure 3 shows the calculated flight tracks of Eagle1 and N1285U. Figure 4 shows the aircraft under SDM ATCT control from 1049 until the time of the collision.



Figure 3. Calculated flight tracks of Eagle1 and N1285U.

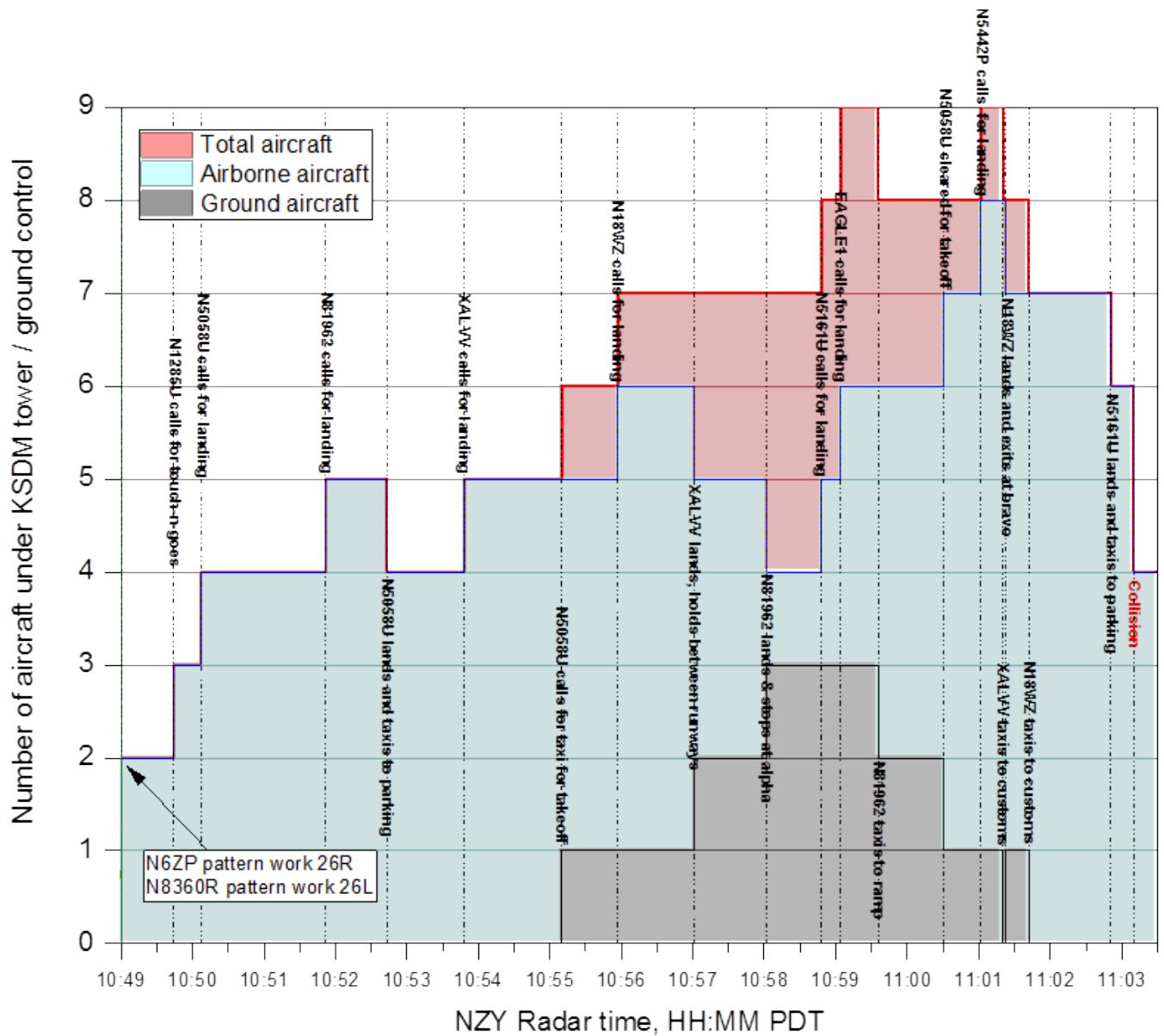


Figure 4. Total aircraft under SDM ATCT control from 1049 until the time of the collision.

Pilot Information

Certificate:	Private	Age:	60, 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 With waivers/limitations	Last FAA Medical Exam:	November 20, 2014
Occupational Pilot:	No	Last Flight Review or Equivalent:	August 10, 2015
Flight Time:	277 hours (Total, all aircraft), 226 hours (Pilot In Command, all aircraft)		

N1285U Pilot

The pilot, age 60, held a private pilot certificate for airplane single-engine land issued on December 2, 1997. His most recent Federal Aviation Administration (FAA) third-class medical certificate was issued on November 20, 2014, with limitations stating that he must wear corrective lenses for near and distant vision. The pilot's logbooks revealed that he had accumulated about 277 total flight hours, including 9.7 hours in the last 6 months.

Eagle1 Pilot (Pilot Monitoring)

The pilot, age 41, held an airline transport pilot certificate issued on April 1, 2011, and a flight instructor certificate issued on November 8, 2008 (most recent renewal on November 25, 2014). He held instructor ratings for airplane multiengine, single-engine, single-engine instrument, and glider. His most recent FAA first-class medical certificate was issued on April 30, 2015, with no limitations. According to BAE, the pilot had about 4,480 total flight hours. In the 90 days before the accident, he logged 18 hours in airplanes, including 4 hours in the accident airplane make and model. His most recent flight review was completed on April 13, 2015. The pilot was seated in the left seat and was acting as the pilot monitoring.

Eagle1 Copilot (Pilot Flying)

The copilot, age 66, held an airline transport pilot certificate issued on March 8, 2005, and a flight instructor certificate issued on October 20, 2009. The copilot held ratings for airplane multiengine and single-engine land. His most recent FAA first-class medical certificate was issued on January 12, 2015, with the limitation that he must wear corrective lenses. According to BAE, the copilot had about 7,150 total flight hours, and his most recent flight review was completed on April 13, 2015. The copilot was seated in the right seat and was acting as the pilot flying.

Local Controller/Controller-in-Charge

The local controller at the time of the accident, age 59, was a certified professional controller and CIC. He had 37 years of ATC experience: 5 years in the US Air Force, 24 years with the FAA, and 8 years with his current employer. He was qualified on all positions in the SDM ATCT on September 18, 2014,

and was certified as an SDM CIC on September 19, 2014. He was designated as an on-the-job training instructor on February 10, 2015. His most recent recurrent training was completed on July 31, 2015, and included, but was not limited to, the topics of runway separation, visual separation, limited aviation weather reporting station (LAWRS), and opposite direction operations. His most recent FAA second-class medical certificate was issued on September 23, 2014, with the limitation that he must wear corrective lenses. He indicated in a postaccident interview that he was in compliance with the limitation at the time of the accident.

Local Control Trainee

The LC trainee, age 27, was qualified on ground and flight data control positions on June 25, 2015. He completed local controller classroom training on June 22, 2015, and started on-the-job training on the local control position on June 27, 2015. His most recent recurrent training was completed on July 31, 2015, and included, but was not limited to, the topics of runway separation, visual separation, LAWRS, and opposite direction operations. His most recent FAA second-class medical certificate was issued on April 28, 2015, with no limitations.

Aircraft and Owner/Operator Information

Aircraft Make:	Cessna	Registration:	N1285U
Model/Series:	172M	Aircraft Category:	Airplane
Year of Manufacture:	1976	Amateur Built:	
Airworthiness Certificate:	Normal	Serial Number:	17266979
Landing Gear Type:	Tricycle	Seats:	
Date/Type of Last Inspection:		Certified Max Gross Wt.:	2299 lbs
Time Since Last Inspection:		Engines:	1 Reciprocating
Airframe Total Time:		Engine Manufacturer:	LYCOMING
ELT:		Engine Model/Series:	O-320 SERIES
Registered Owner:	On file	Rated Power:	0 Horsepower
Operator:	On file	Operating Certificate(s) Held:	None

N1285U Airplane

The white- and yellow-colored Cessna 172M was a high-wing, four-seat airplane manufactured in 1976 and powered by a Lycoming O-320-D2G engine rated at 160 horsepower, installed under RAM Aircraft Modifications supplemental type certificate SA2375SW. The airplane had a gross weight of 2,300 lbs. The most recent annual inspection was conducted on July 15, 2015. At the time of inspection, the airplane had a total time of 9,848.1 flight hours. It was equipped with a rotating beacon light, anticollision strobe lights, navigation position lights, a landing light, and a taxi light. The operational status of each lighting system at the time of the accident could not be determined. N1285U 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 white-colored North American Rockwell NA265-60SC Sabreliner was a low-wing, five-seat airplane manufactured in 1974 and powered by two Pratt and Whitney JT12A-8 turbojet engines, each rated at 3,000 lbs of thrust. The accident airplane was operating with an experimental airworthiness certificate because it had been modified with an external test pod attached to the lower side of the airplane aft of the nose landing gear. The airplane had a maximum gross weight of 22,900 lbs. According to the maintenance records, the most recent annual inspection was conducted on July 20, 2015. At the time of inspection, the airplane had a total time of 13,418 flight hours. The Sabreliner was equipped with a Fairchild GA-100 CVR with 30 minutes of analog audio on a continuous loop tape in a four-channel format. It was equipped with anticollision lights on the vertical tail and under the fuselage just forward of the main wheel well, wing ice inspection lights, strobe and position lights on the tail cone and each wing tip, and landing-taxi lights forward of the nose landing gear. The operational status of each lighting system at the time of the accident could not be determined. The Sabreliner was not equipped with a TAS, TCAS, or ADS-B equipment or displays.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	Condition of Light:	Day
Observation Facility, Elevation:	KSDM, 515 ft msl	Distance from Accident Site:	1 Nautical Miles
Observation Time:	17:53 Local	Direction from Accident Site:	250°
Lowest Cloud Condition:	Clear	Visibility	10 miles
Lowest Ceiling:	None	Visibility (RVR):	
Wind Speed/Gusts:	6 knots / None	Turbulence Type Forecast/Actual:	/
Wind Direction:	310°	Turbulence Severity Forecast/Actual:	/
Altimeter Setting:	29.87 inches Hg	Temperature/Dew Point:	33°C / 19°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	SAN DIEGO/EL CAJON, CA (SEE)	Type of Flight Plan Filed:	None
Destination:	San Diego, CA (SDM)	Type of Clearance:	VFR
Departure Time:	10:30 Local	Type of Airspace:	Class D

The 1053 SDM automated weather observation included wind from 310°; at 6 knots, visibility 10 statute miles, clear skies, temperature 33°; C, dew point 19°; C, and an altimeter setting of 29.87 inches of mercury.

Airport Information

Airport:	BROWN FIELD MUNI SDM	Runway Surface Type:	Asphalt
Airport Elevation:	526 ft msl	Runway Surface Condition:	Dry
Runway Used:	26L	IFR Approach:	None
Runway Length/Width:	3180 ft / 75 ft	VFR Approach/Landing:	Traffic pattern

SDM is located about 14 nm southeast of San Diego on the Otay Mesa at an elevation of 526 ft msl. The rising terrain associated with the Otay Mountain peaks begins about 2 miles east-northeast of SDM, and the highest terrain, at an elevation of 3,566 ft msl, is located about 8 miles east of SDM. Designated skydiving areas are located at SDM and at a second location about 3 miles east of SDM (see figure 5).

SDM has two parallel runways. Runway 8L/26R measures about 7,972 ft long and 150 ft wide, and runway 8R/26L measures about 3,180 ft long and 75 ft wide. Although the published traffic pattern for 26R is right traffic, it is common in west operations for controllers to use a right traffic pattern for both runways 26R and 26L due to the proximity of Tijuana Airport, Tijuana, Mexico, to the south of SDM. Some helicopter traffic is assigned to use a left traffic pattern for runways 26L and 26R. The published VFR pattern altitude at SDM is 1,526 ft for runway 8L/26R and 1,126 ft for runway 8R/26L. SDM operates within class D airspace, which includes the airspace extending upward from the surface to and including 3,000 ft msl within a 2.6-mile radius of SDM. (These dimensions are nonstandard; the normal radius is around 5 miles.)

The SDM ATCT is a nonapproach control federal contract tower, operated and staffed by a private company. Local controllers at nonapproach control towers must devote the majority of their time to visually scanning the runways and local area. The SDM ATCT employed five controllers; at the time of the accident, the ATCT was operating and had three controllers in the facility, which was the normal staffing schedule for that day and time. Both accident airplanes were operating under VFR in the class D airspace and were communicating with and being provided ATC services by SDM ATCT personnel. After the accident, on August 26, 2015, the SDM ATCT issued a corrective action plan regarding inconsistencies in how controllers were issuing traffic advisories and safety alerts. The plan required controllers to review FAA JO 7110.65V, Air Traffic Control, paragraphs 2-1-6 and 2-1-21, as refresher training before working an operational position.



Figure 5. FAA sectional aeronautical chart view depicting SDM and the approximate accident location. (Not for navigational use.)

Wreckage and Impact Information

Crew Injuries:	1 Fatal	Aircraft Damage:	Destroyed
Passenger Injuries:		Aircraft Fire:	Both in-flight and on-ground
Ground Injuries:	N/A	Aircraft Explosion:	Both in-flight and on-ground
Total Injuries:	1 Fatal	Latitude, Longitude:	32.577499,-116.94889(est)

The wreckage was located in a large open area about 1 1/2 miles northeast of SDM and consisted of two primary debris fields, one for each airplane.

N1285U Airplane

N1285U's debris field, which was about 1,200 ft long and aligned on a magnetic heading of 055°, contained some components and fragments from Eagle1 and was located about 400 ft northeast of the Eagle1 debris field. The N1285U main wreckage contained the engine, propeller, and part of the main cabin. The main cabin wreckage consisted of parts of the floor, seats, and cabin structure. The engine remained partially attached to the firewall and exhibited impact damage to its left side, revealing

cylinder components. The propeller assembly was found separated from the engine and partially buried in a small crater. The propeller was heavily gouged in multiple directions, and one blade had aft bending.

The left wing remained attached to a portion of the cabin roof and came to rest inverted. The wing and roof section had thermal damage. The flap and aileron remained attached to the wing. The inboard portion of the leading edge of the left wing displayed impact damage and red transfer marks. The fuselage and right wing were highly fragmented and spread throughout the debris field.

Eagle1

Most of the Eagle1 wreckage was contained within a radius of about 100 ft; no parts from N1285U were located within that radius. The Eagle1 main wreckage was on a magnetic heading of 060° and consisted of the cabin area, left wing, empennage, both engines, and the externally mounted test pod. The forward cabin area came to rest on its upper left side and was crushed. The remaining cabin area was crushed and had thermal damage. The left wing came to rest on its trailing edge, supported at an angle by the landing gear. Both engines were found near the tail section and displayed crush damage. The test pod and internal equipment had impact and thermal damage.

The Eagle1 right wing was found on a road near the N1285U debris field, about 400 ft north of the Eagle1 main wreckage. A power transmission line near the wing's location was separated during the accident. The wing displayed leading-edge damage from near the tip to the separation point from the inboard portion of the wing. About 4 ft of the inboard wing was separated and recovered with the main wreckage. A 5-ft section of leading edge, from the stall fence inboard, displayed leading-edge damage revealing the internal surfaces of the wing. The lower surface of the wing displayed metallic impact marks and paint transfer marks.

Follow-up Examination

Detailed examination of the wreckage from both airplanes was conducted at a secure facility several days after the accident. The right wing of Eagle1 was positioned with the N1285U wreckage, and investigators conducted an examination for contact evidence between the airplanes. The Eagle1 right wing had impact marks consistent with the impact of N1285U's engine. Specifically, the spacing of the impact marks on the inboard lower surface of the Eagle1 right wing were consistent with the spacing of the N1285U engine crankcase upper studs, flanges, and engine lifting eye. The angle of the marks relative to the Eagle1's longitudinal axis was about 30° and indicates that this was the convergence angle between the airplanes. The damage on the N1285U crankcase upper studs, flanges, and engine lifting eye was consistent with impact from its left side and with the computed convergence angle.

In addition, the conformity of the Cessna fuselage, wing strut, and wing spar damage to the Eagle1 wing shape indicates that the Eagle1 right wing impacted the left side of the Cessna. The evidence is consistent with the longitudinal axes of the two airplanes being approximately perpendicular to one another at the time of impact, with Eagle1 approaching the Cessna from the left, and with the Eagle1 right wing below the Cessna left wing.

The reconstruction of the airplanes' flightpaths, based on radar data, is described in the NTSB's Aircraft

Performance and Cockpit Visibility Study for this accident. The collision geometry resulting from the trajectory reconstruction is consistent with the collision geometry indicated by the wreckage examination.

Flight recorders

Cockpit Voice Recorder

The CVR was recovered from the Eagle1 wreckage and forwarded to the National Transportation Safety Board (NTSB) vehicle recorders laboratory in Washington, DC, for readout. The CVR had 30 minutes of analog audio on a continuous loop tape in a four-channel format: one channel for each of the two pilot stations, one channel for the cockpit observer station, and one channel for the cockpit area microphone (CAM). The magnetic tape was retrieved from within the crash-protected case and was successfully downloaded.

The quality of the CVR audio information was degraded due to the erase mechanism not completely erasing the previous recordings, especially on the CAM channel. Timing on the transcript was established by correlating the CVR events to the common events recorded by SDM ATC. The CVR recording started at 1032:28 and ended at 1103:10. Due to the poor quality of the CVR recording, the SDM ATC transcript was used in conjunction with the CVR recording to clarify the flight crew's radio transmissions.

Medical and Pathological Information

The FAA's Civil Aerospace Medical Institute performed toxicology testing on tissue specimens from the three pilots. The specimens tested negative for ethanol and major drugs of abuse.

The LC and LC trainee on duty at the time of the accident tested negative for drugs and alcohol.

Tests and Research

Aircraft Performance and Cockpit Visibility Study

The NTSB's investigation examined the ability of the N1285U and Eagle1 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. Position and

orientation information for both airplanes was estimated based on an analysis of the radar data, combined with models of each airplane's aerodynamic performance. For this study, the relative positions of the two aircraft were calculated beginning at 1100:06.0 and then at 0.05-second intervals up to the collision, which occurred at 1103:10.2. The time, location, and altitude of the collision were determined based on extrapolation of the radar data, the wreckage locations of both aircraft, and the time of the end of Eagle1's CVR recording. The locations of the structures and transparencies of Eagle1 in its copilot's (right seat) field of view, and of N1285U in its pilot's (left seat) field 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 study assumed a nominal pilot seating (and eye) position in each cockpit and evaluated a matrix of eye displacements from the nominal eye position. The variations in eye position indicated that pilot head movements can move the target airplane's position in the field of view into and out of areas that are obscured from the pilots. For Eagle1, the visibility of N1285U from the copilot's seat is sensitive to the pilot's eye position relative to the top and left edges of the Eagle1 R2 window, and for N1285U, the visibility of Eagle1 is sensitive to the pilot's eye position relative to the post between the left door window and the windshield (see figure 6 for a top-down view of the Eagle1 forward fuselage with cockpit windows labeled). The description of the visibility from each aircraft that follows is based on the pilots' eyes at "nominal" positions, determined by the eye positions of persons of similar stature to the accident pilots seated in exemplar airplanes. The Aircraft Performance and Cockpit Visibility Study for this accident describes how the visibility from each airplane changes with variation in eye position and notes that head movements in several directions while scanning for traffic can make otherwise obscured aircraft visible.

Eagle1's 10 cockpit windows (5 on each side of the airplane) are labeled L1 through L5 for the left windows and R1 through R5 for the right windows, as shown in figure 6. The Cessna windows are the windshield, left window, and right window.

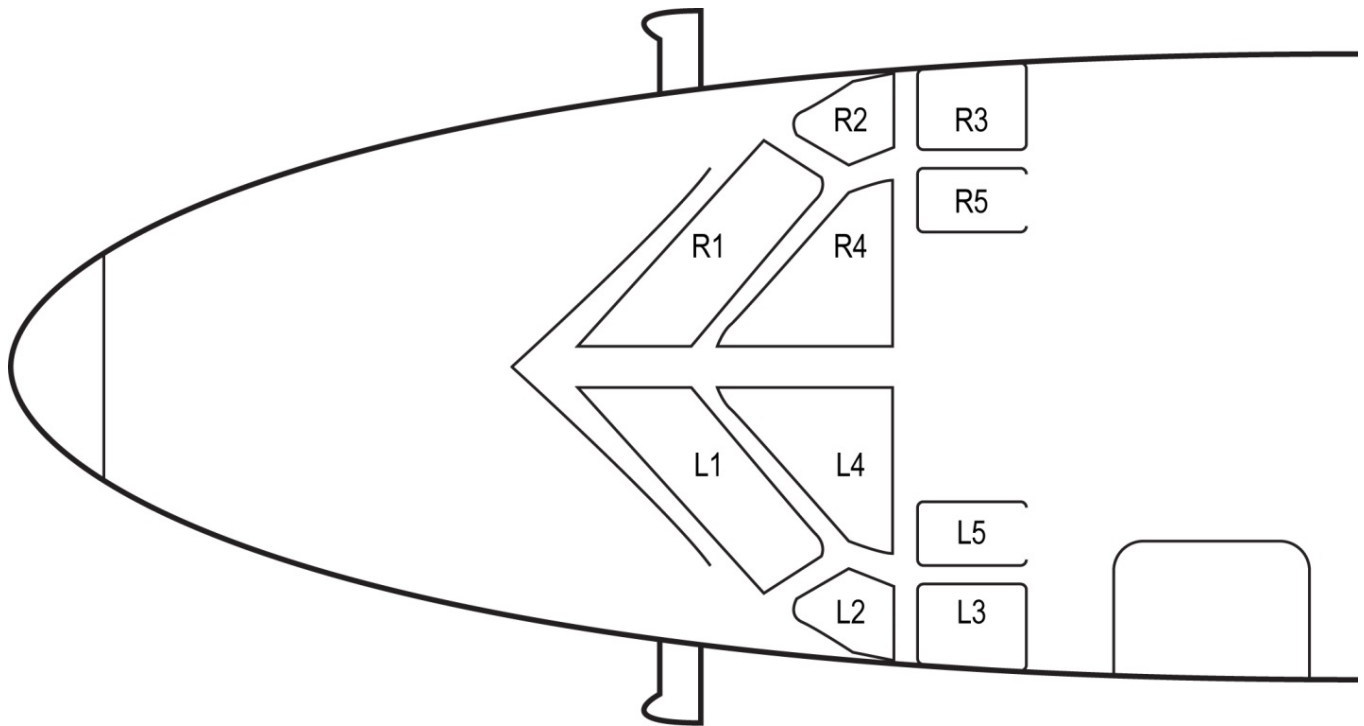


Figure 6. Top-down view of Eagle1 forward fuselage, showing labels used to identify cockpit windows.

At 1100:06, N1285U was climbing through 540 ft over runway 26L after completing its touch-and-go operation, and Eagle1 was 6 nm west and 1 nm north of the SDM runway 26R threshold, descending through 2,380 ft.

At 1100:29, Eagle1's CVR recorded the copilot comment "got one on short final" (likely Global Express N18WZ), and Eagle1 was descending through 2,260 ft, 1 nm north and 4.9 nm west of the runway 26R threshold. N1285U was climbing through 780 ft, along the extended centerline of runway 26L, and about 800 ft past the departure end of that runway. N1285U would have been located in Eagle1's R1 window. The other aircraft in the pattern would have been located in roughly the same area, except for the other Cessna 172, N6ZP, which was to the left in the R1 window. Eagle1 would have appeared in N1285U's windshield. The aircraft were 4.1 nm apart.

At 1100:55, N1285U was climbing through 1,150 ft about 1,200 ft west of the departure end of runway 26R and began a right turn to cross over the extended centerline of 26R to enter the right traffic pattern for that runway. Eagle1 was at 2,190 ft, about 1 nm north and 3.6 nm west of the runway 26R threshold, about 2.4 nm from N1285U, and would have been located in N1285U's windshield about in line with the top of the instrument panel. N1285U would have been located in Eagle1's R1 window.

At 1101:15.5, Eagle1's CVR recorded the copilot state "got one on the runway" (likely N18WZ). At this

time, N18WZ may have been obscured behind the post separating Eagle1's R1 and R2 windows, if the copilot's eyes had been looking from the "nominal" position. Since the copilot saw and commented on N18WZ, however, he may have been leaning closer to the window to scan for traffic, bringing N18WZ more into view. N1285U would have appeared in Eagle1's R2 window and was 1.2 nm away. Eagle1 would have appeared in the N1285U pilot's field of view near the forward edge of the post separating the left window from the windshield.

At 1101:24.6, Eagle1 was level at 2,100 ft, about 1 nm north and 2.4 nm west of the runway 26R threshold, when the pilot stated "I got twelve o'clock on a climb out." At this time, the Cessna 206 (N5058U) had recently departed from runway 26L. N1285U was 0.8 nm from Eagle1, climbing through 1,600 ft and turning from crosswind to right downwind for runway 26R, 0.5 nm north and 1.7 nm west of the runway 26R threshold. N1285U would have appeared in Eagle1's R2 window; N5058U would have appeared slightly below and to the left of N1285U. Eagle1 would have been hidden from the N1285U pilot's view behind the window post between the left window and windshield.

At 1101:43.1, N1285U would have been located just to the left of the window post separating Eagle1's R2 and R3 windows, and N5058U would have been just to the right of this post (see figure 7a). Eagle1 would have appeared in the left window of N1285U, just below the wingtip (see figure 7b). Eagle1 and N1285U were both on the right downwind leg for runway 26R, with Eagle1 about 0.4 nm north of N1285U.

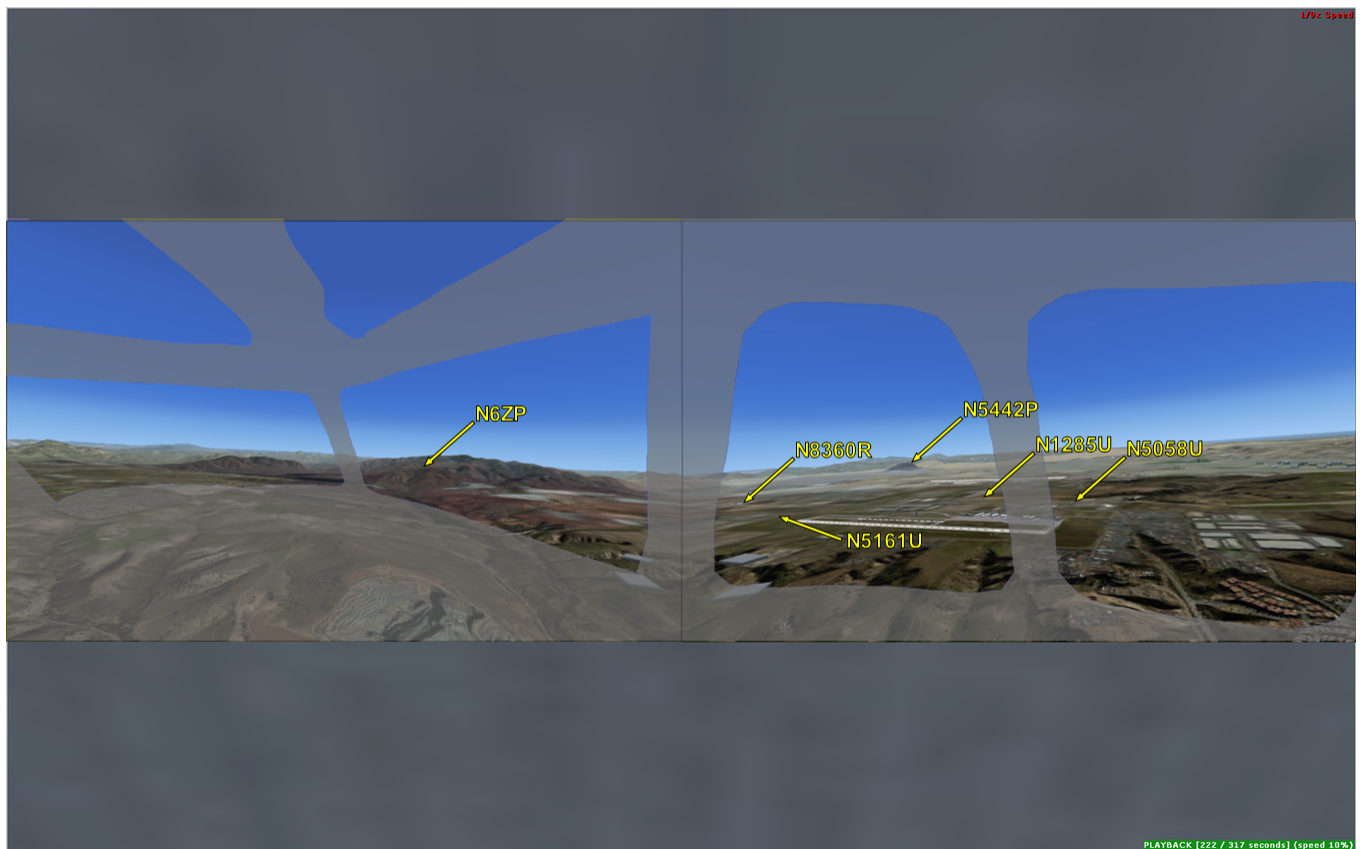


Figure 7a. View from the copilot seat of Eagle1 at 1101:43.1, when the airplanes were 0.5 nm apart.

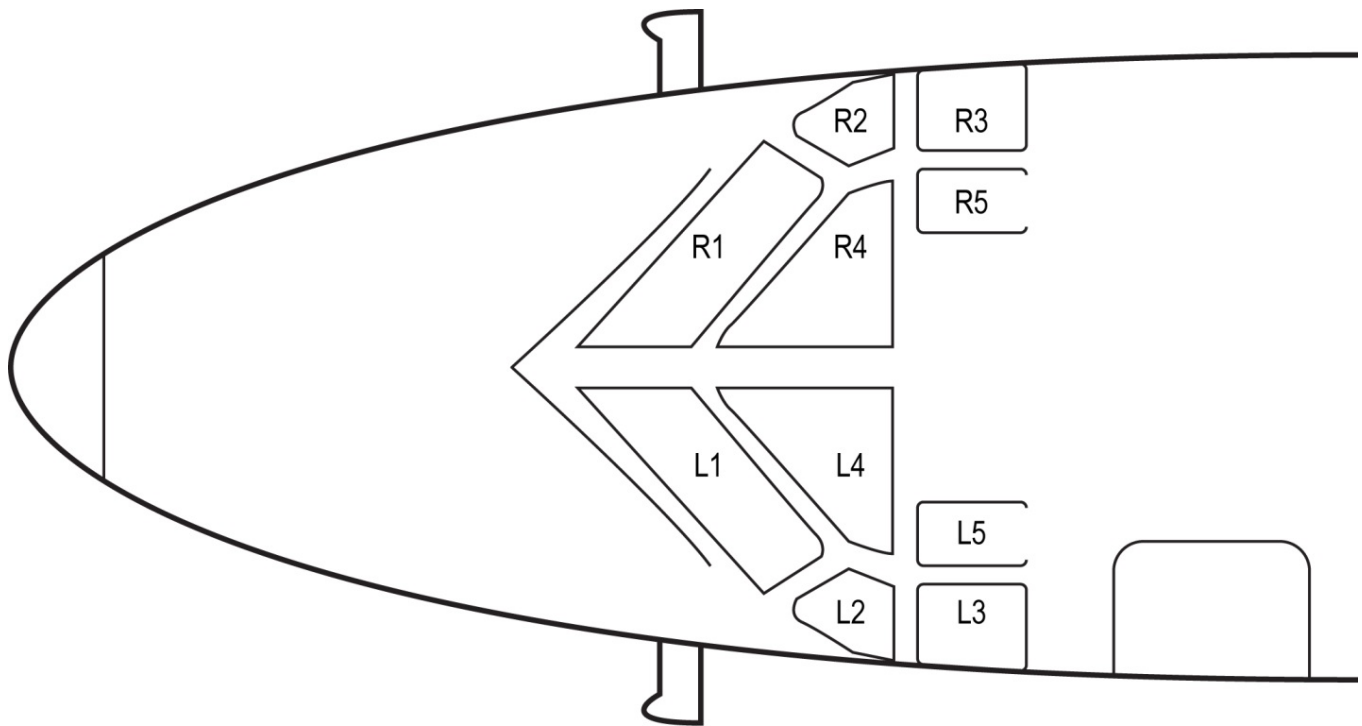


Figure 7b. View from the pilot seat of N1285U at 1101:43.1, when the airplanes were 0.5 nm apart.

At 1101:49.0, Eagle1's CVR recorded one of the mission specialists seated outside of the cockpit ask "see him right there?" Eagle1 was at about 2,040 ft, 1.1 nm north and 1.4 nm west of the runway 26R threshold. N1285U was level at 1,700 ft, 0.7 nm north and 1.3 nm west of the threshold. The airplanes were about 0.5 nm apart, and N1285U would have appeared in Eagle1's R3 window near the right edge of the post separating the R2 and R3 windows. Eagle1 would have been obscured from the N1285U pilot's view by the left wing.

At 1102:14.0, when the Eagle1 flight crew reported "...right downwind abeam. traffic to the left and right in sight," Eagle1 was at about 2,110 ft, 1.3 nm north and 0.4 nm west of the runway 26R threshold. N6ZP would have appeared in Eagle1's L1 window and was the only aircraft to Eagle1's left. N1285U would have appeared in Eagle1's R3 window. N1285U was descending through 1,650 ft, about 0.7 nm north and 0.5 nm west of the runway 26R threshold. Eagle1 would have remained obscured from the N1285U pilot's view by the left wing. Other airborne traffic to the right of Eagle1 at this time included a

Piper airplane (N5442P), the helicopter (N8360R), and the Cessna 206 (N5058U).

At 1102:32.0, when the LC mistakenly instructed N6ZP to make a right 360° turn, intending the instruction for N1285U, Eagle1's CVR recorded the pilot ask "you still got the guy on the right side?" N1285U was 0.8 nm away and would have appeared in Eagle1's R3 window (see figure 8a). Also to Eagle1's right were N8360R (on short final approach for runway 26L), N5442P (on a left base leg for runway 26L), and N5058U (which was climbing through 1,500 ft about 2.6 nm to the west of the runway 26R threshold). Eagle1 would have been obscured from the N1285U pilot's field of view by the left wing and strut (see figure 8b). Eagle1 started banking to the right, turning toward right base, shortly after this time.

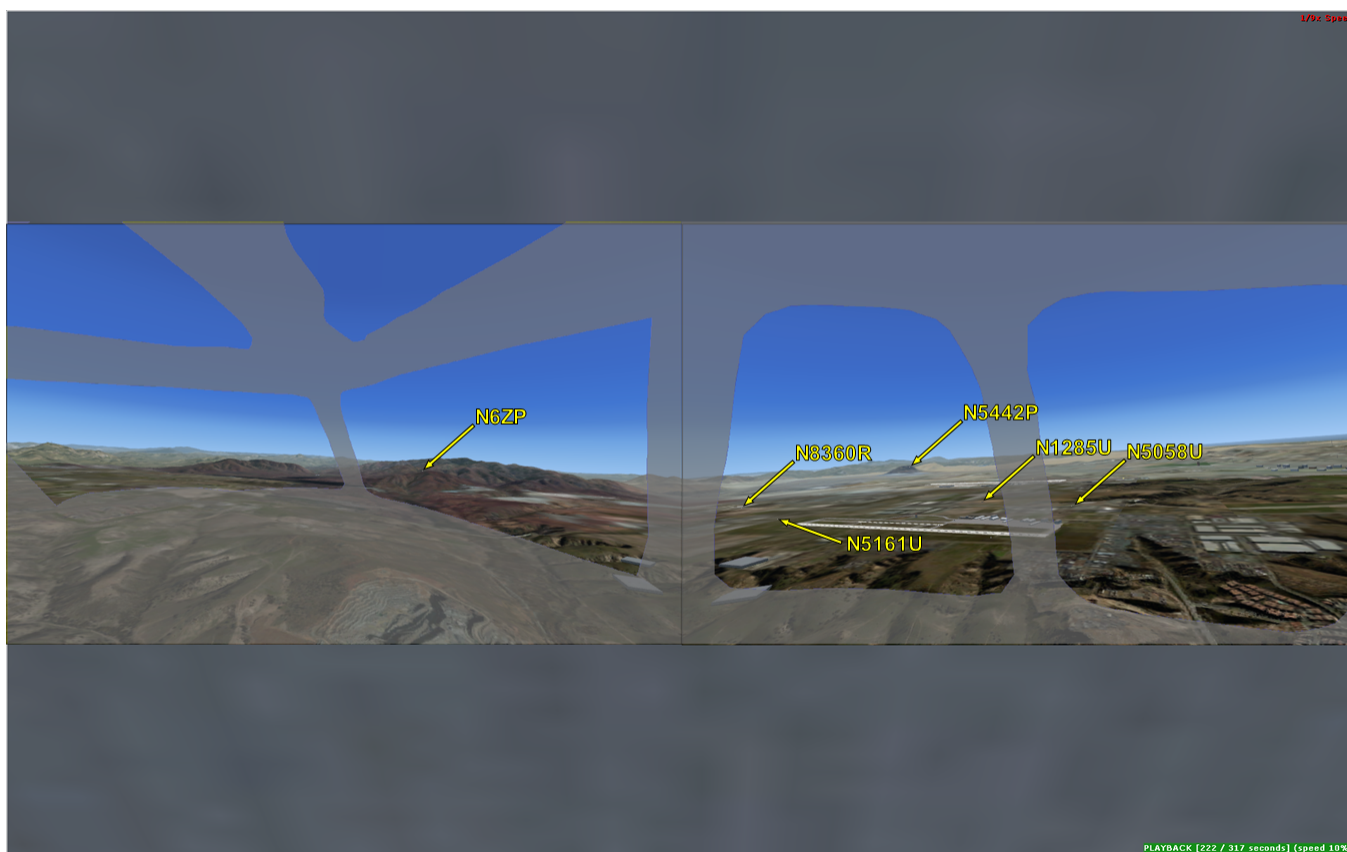


Figure 8a. View from the copilot seat of Eagle1 at 1102:32.4, when the airplanes were 0.8 nm apart.

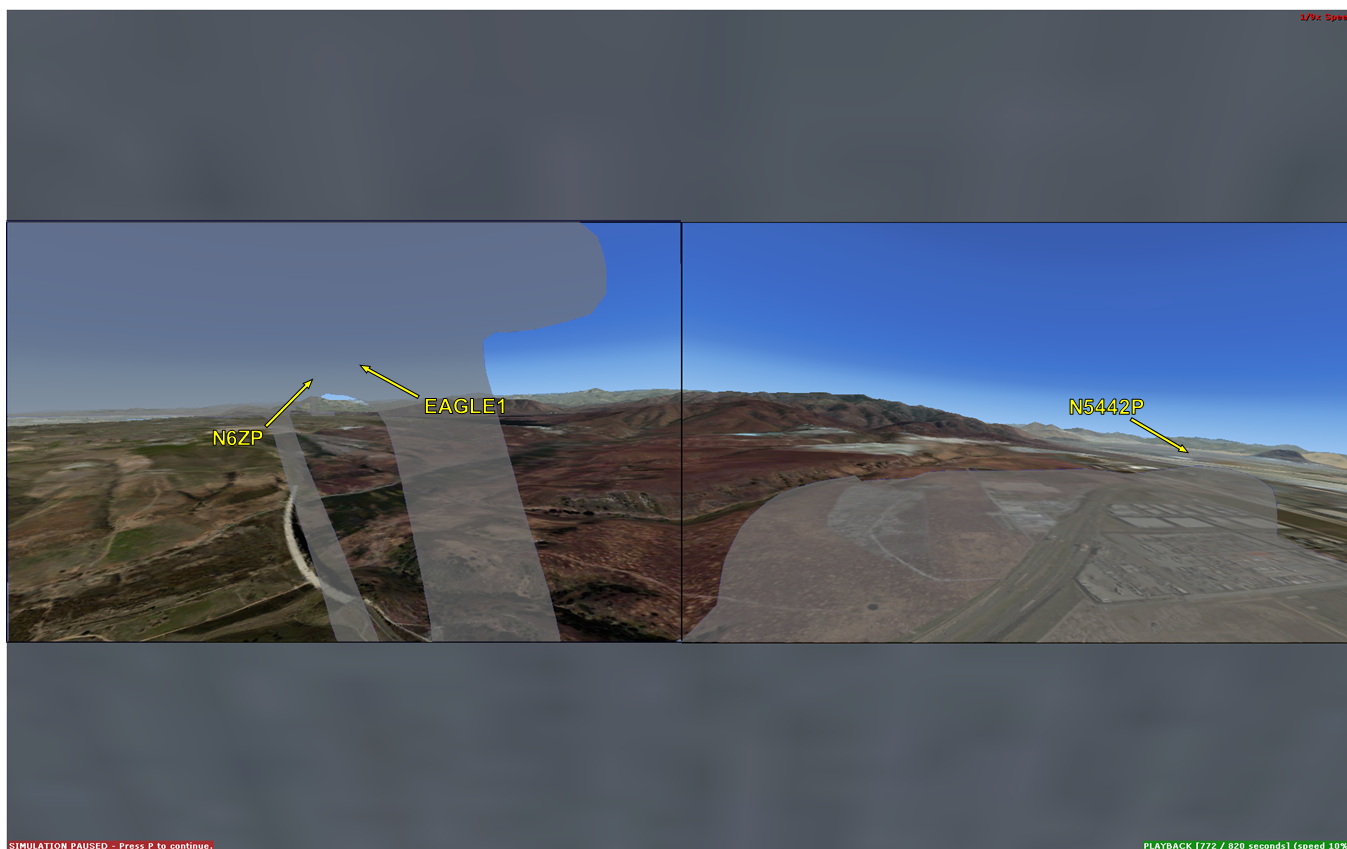


Figure 8b. View from the pilot seat of N1285U at 1102:32.4, when the airplanes were 0.8 nm apart.

At 1102:42.0, when the LC instructed the pilot of Eagle1 to "turn base two six right cleared to land," Eagle1 was descending through 1,960 ft in a right bank, about 1.3 nm north and 0.7 nm east of the runway 26R threshold. N1285U was descending through 1,460 ft, about 0.6 nm north and 0.3 nm east of the threshold, and would have appeared in Eagle1's R3 window (see figure 9a). Eagle1 would have appeared in the N1285U pilot's field of view near the edge or slightly behind the window post separating the left window from the windshield (see figure 9b). The airplanes were still about 0.8 nm away from each other.

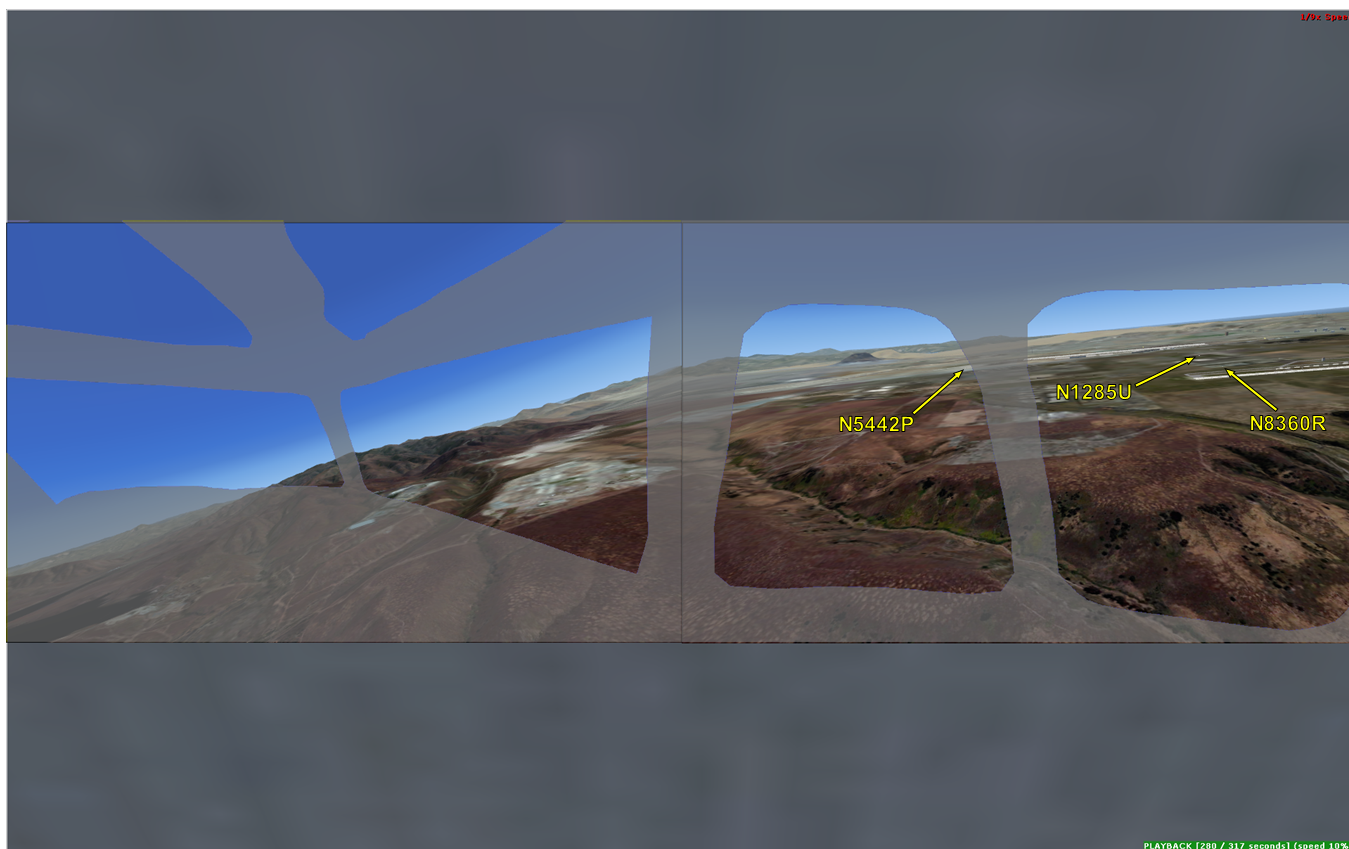


Figure 9a. View from the copilot seat of Eagle1 at 1102:42.0, when the airplanes were 0.8 nm apart.

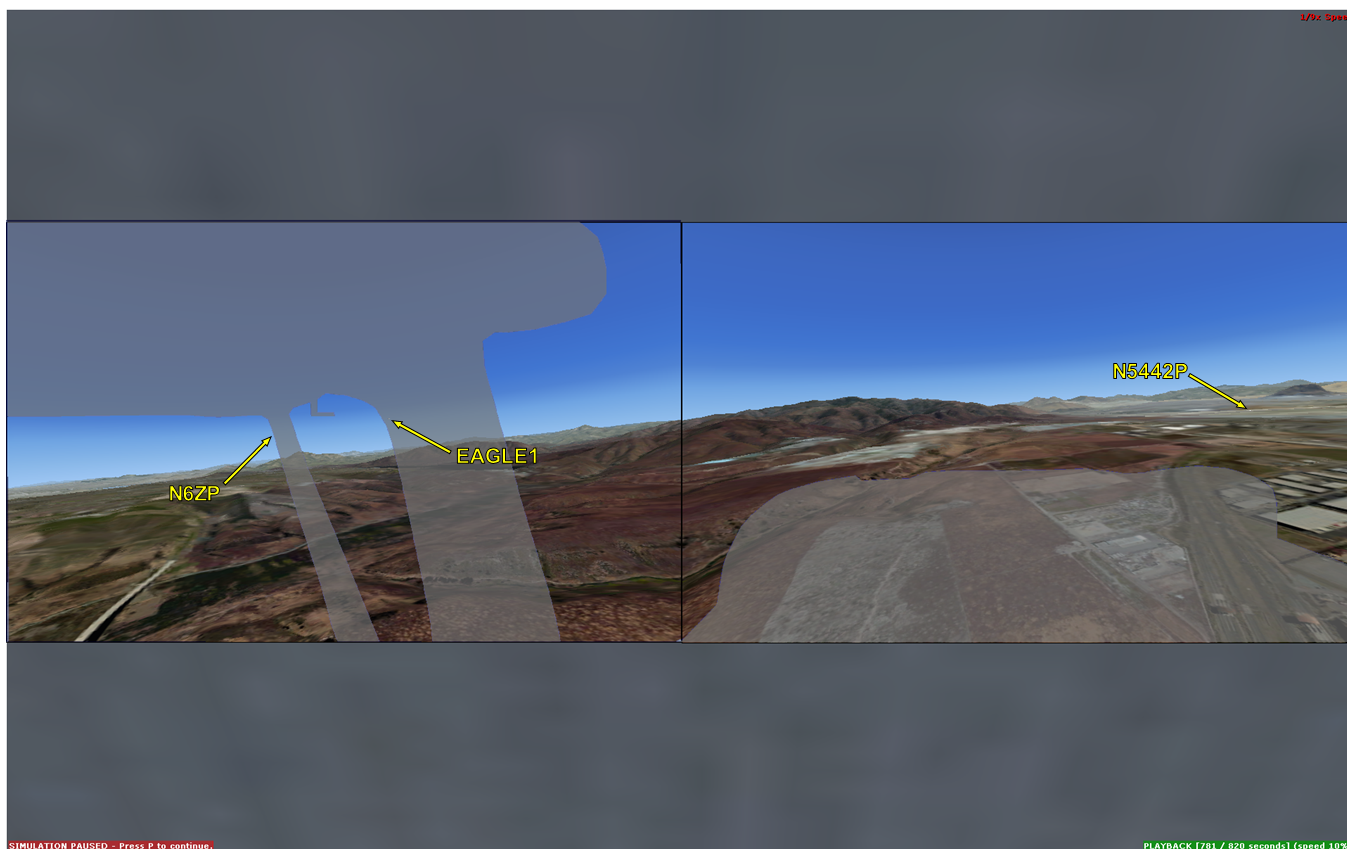


Figure 9b. View from the pilot seat of N1285U at 1102:42.0, when the airplanes were 0.8 nm apart.

At 1102:59.3, Eagle1's CVR recorded the pilot state "I see the shadow but I don't see him." The only aircraft close enough to Eagle1 to cast a shadow visible to Eagle1's pilot was N1285U, which was 0.5 nm away and would have appeared in the upper part of Eagle1's R2 window. At this time, Eagle1 may again have been obscured from the N1285U pilot's view by the post between the right window and the windshield.

At 1103:04.0, when the LC called N1285U, apparently realizing that he may have instructed the wrong airplane to make the right 360° turn, Eagle1 and N1285U were 0.3 nm apart, with Eagle1 descending through 1,490 ft and N1285U descending through 1,370 ft. N1285U would have appeared near the top left corner of Eagle1's R2 window, and Eagle1 may have remained obscured behind N1285U's left window post.

At 1103:08.0, when the controller asked the N1285U pilot if he was still on downwind, Eagle1 and N1285U were about 0.1 nm apart. N1285U may have been obscured by the post between Eagle1's R1 and R2 windows, and Eagle1 may have been obscured by N1285U's window post (see figures 10a and 10b).

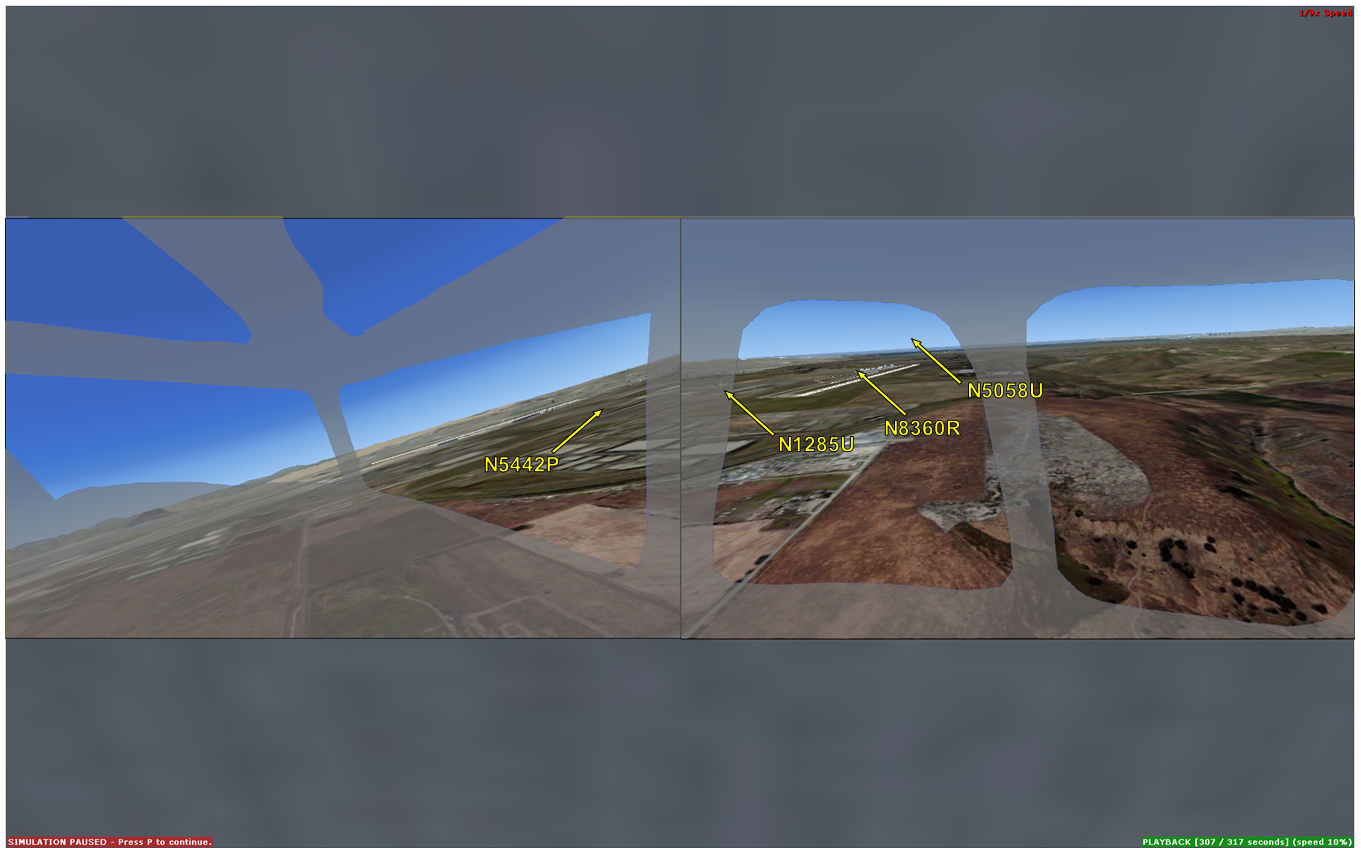


Figure 10a. View from the copilot seat of Eagle1 at 1103:08.0, when the airplanes were 0.1 nm apart.

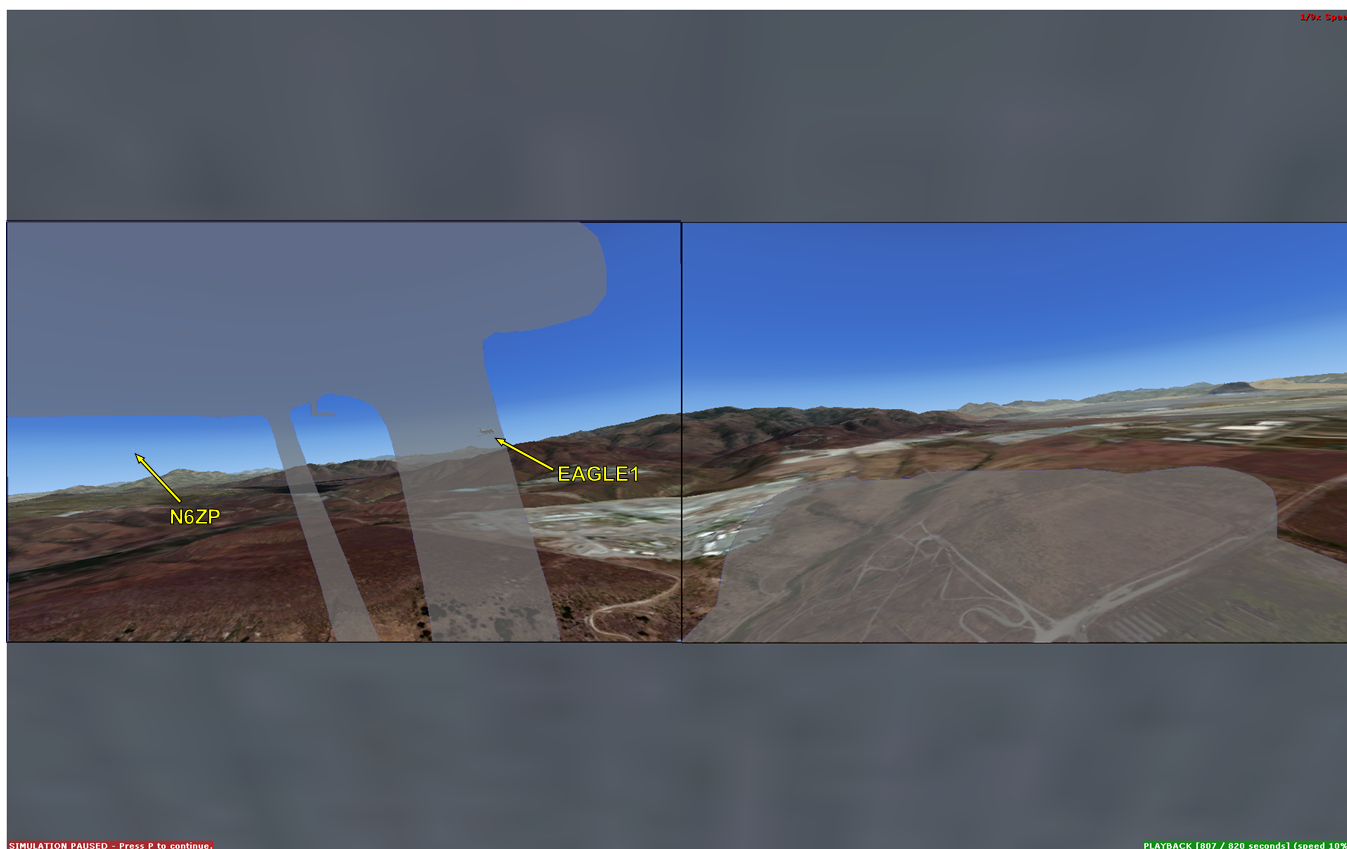


Figure 10b. View from the pilot seat of N1285U at 1103:08.0, when the airplanes were 0.1 nm apart.

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 transmit 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 pilots' 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.

For this accident, simulated in-cockpit displays of traffic information for both Eagle1 and N1285U were created based on the TIS-B information that would have been displayed to the pilots 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, 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 images from the NTSB's in-cockpit traffic display simulation presented in figures 11 through 13 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). In addition, the aircraft N numbers shown in figures 11 through 13 are included here for clarity but would not be presented in an actual display because none of the aircraft in the SDM pattern (except for N18WZ) were ADS-B Out equipped (an actual display could include the N number for N18WZ).

The NTSB's in-cockpit traffic display simulation for Eagle1 indicates that at 1059:04, open (outlined), cyan-colored, arrowhead-shaped targets representing the local traffic at SDM would have appeared at the 1 o'clock position, 8 nm from Eagle1, and traffic inbound for the San Diego area would have appeared at Eagle1's 9 to 11 o'clock position, 8 nm from Eagle1. N1285U would have been depicted 500 ft below Eagle1 east of the airport on a final approach leg. As Eagle1 continued its east-bound track toward SDM, N1285U would have disappeared from view (loss of radar contact). At 1059:48, as Eagle1 approached 6 nm from SDM, N6ZP would have appeared over SDM as an open arrowhead and turned right to remain in the traffic pattern for runway 26R. At 1100:16, N6ZP would have changed to a filled cyan-colored arrowhead before becoming established on the downwind leg at 1100:49. (N6ZP would eventually cross over the projected flightpath of Eagle1 at 1101:49, headed northeastbound.) At 1100:57, when Eagle1 was about 3.5 nm from the runway 26R threshold, N1285U would have reappeared on Eagle1's display as a filled, cyan-colored arrowhead at Eagle1's 1 o'clock position, about 2.5 nm from and 1,100 ft below Eagle1. At 1101:38, N1285U's symbol would have changed to alert status (a filled, yellow-colored arrowhead, enclosed by a yellow circle), and Eagle1 would have received an aural alert advising, "Traffic, 2 o'clock, low, less than 1 mile, climbing" (see figure 11).

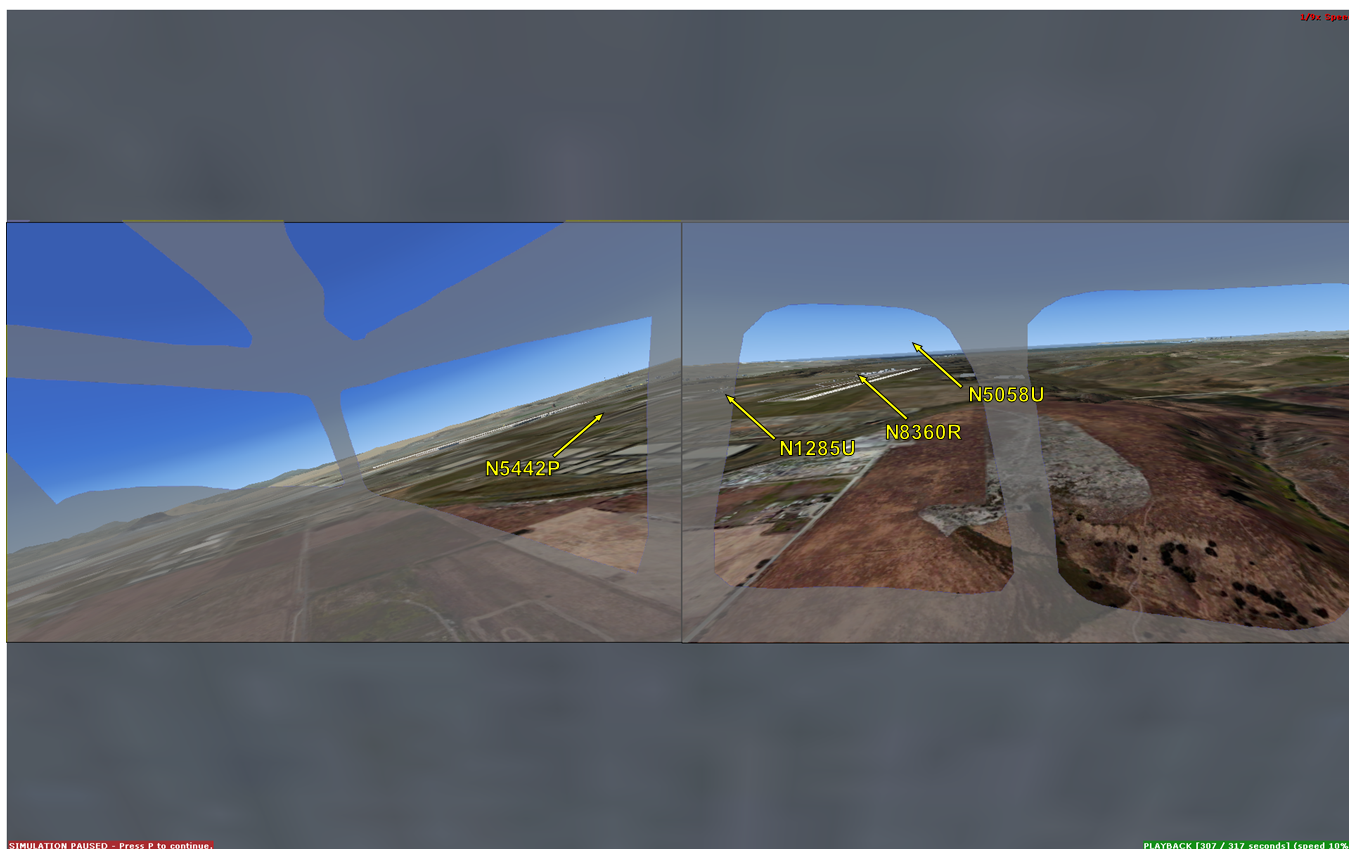


Figure 11. Simulated in-cockpit traffic display for Eagle1 at 1059:04 (left) and 1101:38 (right).

As shown in figure 12, at 1101:38, as N1285U turned onto the downwind leg and as Eagle1 was receiving its aural alert, N1285U's display would have depicted Eagle1 at N1285U's 8 o'clock position, 0.6 nm from and 400 ft above N1285U. At 1102:14, both Eagle1 and N1285U were positioned abeam the tower, and Eagle1 reported traffic to the left and right in sight. N6ZP would also have been shown on the displays departing the SDM area heading in a northeastern direction 400 ft above N1285U and at the same altitude as Eagle1.

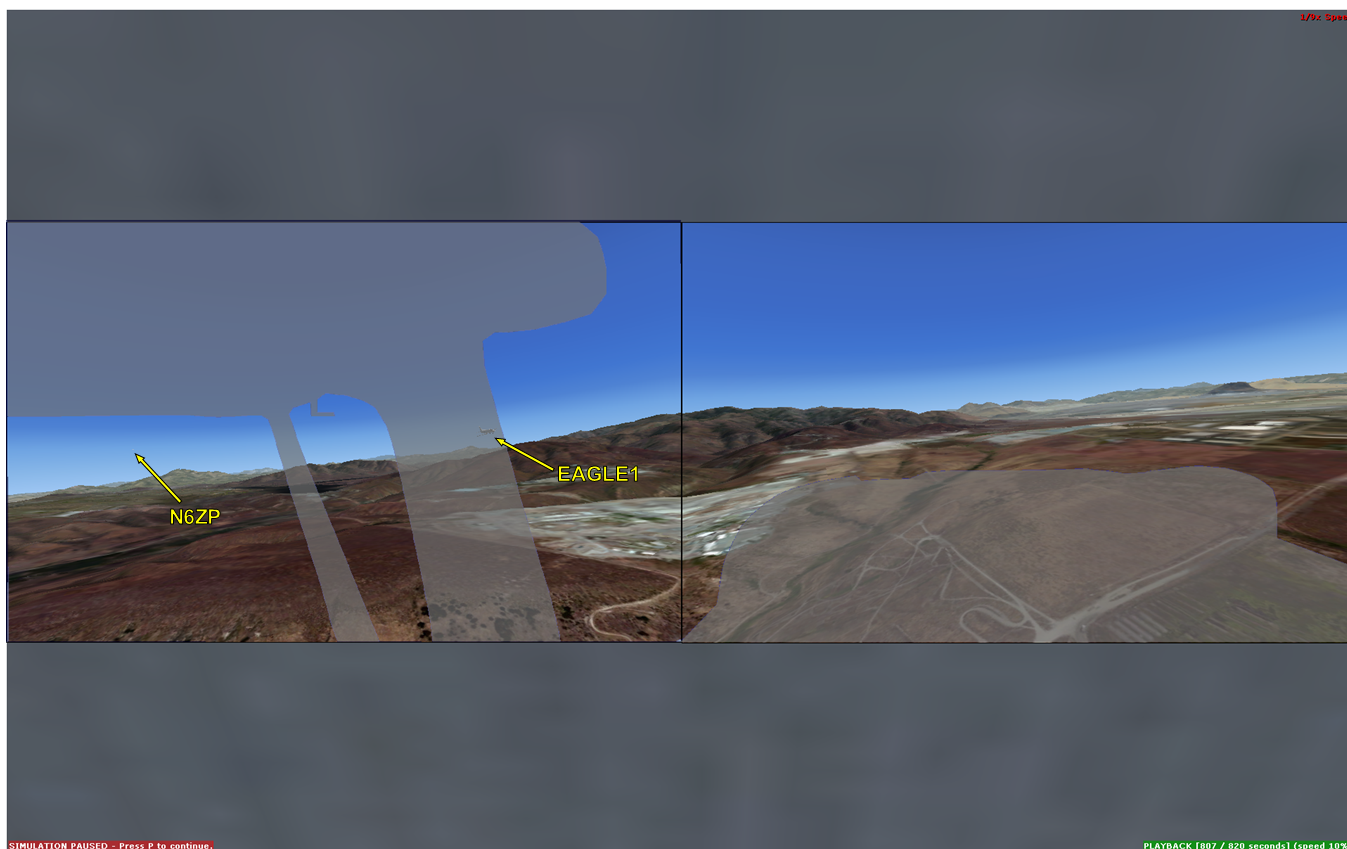


Figure 12. Simulated in-cockpit traffic display for N1285U at 1101:38 (left) and 1102:14 (right).

At 1102:59.3, during Eagle1's base turn, the pilot stated, "I see the shadow but I don't see him." At this time, N1285U would have been depicted on Eagle1's display at Eagle1's 2 o'clock position, between Eagle1 and the runway 26R threshold, 1 nm from and 500 ft below Eagle1. At 1103:07, about 3 seconds before the collision, N1285U would have again changed to alert status (yellow, circled arrowhead), and Eagle1 would have received a second aural alert advising, "Traffic, 1 o'clock, same altitude, zero miles" (see figure 13). At the same time, Eagle1 would have changed to alert status on N1285U's display, and N1285U would have received an aural alert advising, "Traffic, 11 o'clock, same altitude, zero miles, descending." Additional details about the traffic information that could have been displayed during the accident scenario can be found in the Aircraft Performance and Cockpit Visibility Study.

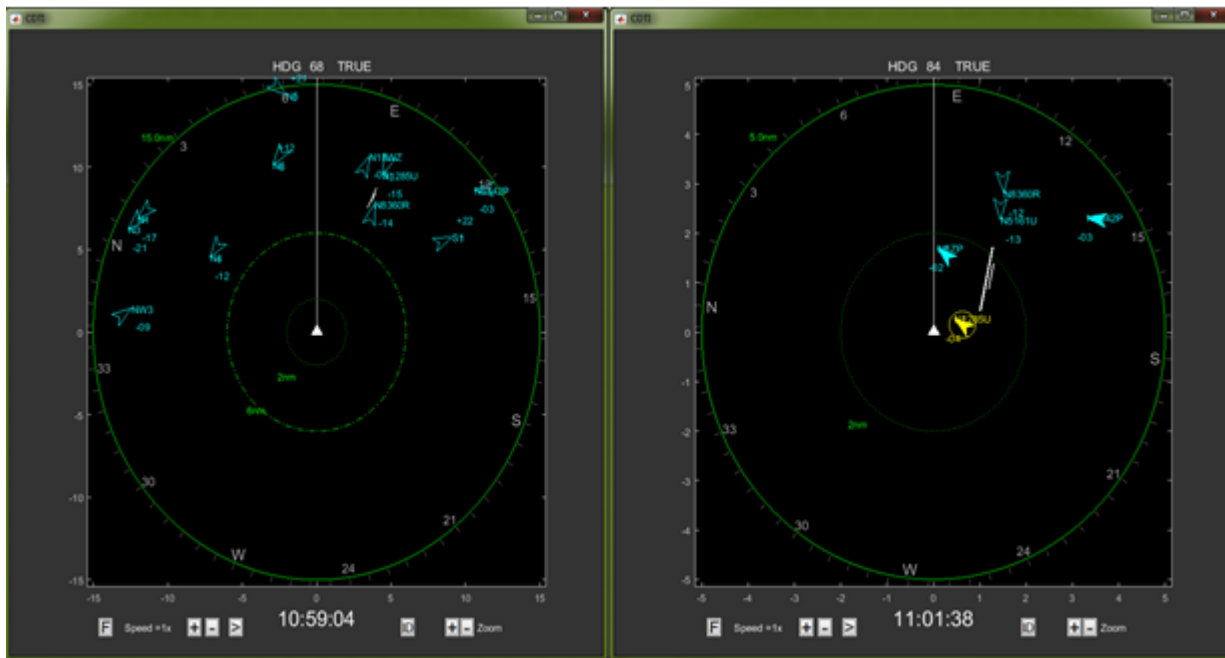


Figure 13. Simulated in-cockpit traffic display for Eagle1 at 1102:59 (left) and 1103:07 (right).

Additional Information

FAA 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 4-1-16, describes the manner in which pilots could expect to receive traffic safety alerts from ATC and states, in part, the following:

A safety alert will be issued to pilots of aircraft being controlled by ATC if the controller is aware the aircraft is at an altitude which, in the controller's judgment, places the aircraft in unsafe proximity to

terrain, obstructions or other aircraft. The provision of this service is contingent upon the capability of the controller to have an awareness of a situation involving unsafe proximity to terrain, obstructions and uncontrolled aircraft. The issuance of a safety alert cannot be mandated, but it can be expected on a reasonable, though intermittent basis. Once the alert is issued, it is solely the pilot's prerogative to determine what course of action, if any, to take. This procedure is intended for use in time critical situations where aircraft safety is in question. Noncritical situations should be handled via the normal traffic alert procedures....

Controllers will immediately issue an alert to the pilot of an aircraft under their control if they are aware of another aircraft which is not under their control, at an altitude which, in the controller's judgment, places both aircraft in unsafe proximity to each other. With the alert, when feasible, the controller will offer the pilot the position of the traffic if time permits and an alternate course(s) of action.

Title 14 CFR 91.123, "Compliance with ATC Clearances and Instructions," states the following:

(a) When an ATC clearance has been obtained, no pilot in command may deviate from that clearance unless an amended clearance is obtained, an emergency exists, or the deviation is in response to a traffic alert and collision avoidance system resolution advisory. However, except in Class A airspace, a pilot may cancel an IFR flight plan if the operation is being conducted in VFR weather conditions. When a pilot is uncertain of an ATC clearance, that pilot shall immediately request clarification from ATC.

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, 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 instrument flight rules 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.

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 [Intermittent Positive Control] IPC/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.

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 2-1-6, "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.

Research on Workload

According to Mica R. Endsley and Mark D. Rodgers in a 1997 report titled *Distribution of Attention, Situation Awareness, and Workload in a Passive Air Traffic Control Task: Implications for Operational Errors and Automation* (FAA Report No. DOT/FAA/AM-97/13), the cognitive effects of increasing workload may include memory deficits, distraction, narrowing of attention, decreased situational awareness, and increased errors (such as readback errors or giving instruction to the wrong aircraft). Specifically, Endsley and Rodgers write the following:

This study reveals many interesting findings on the role of situation awareness and workload in operational errors. Significant deficiencies in the ongoing situation awareness of the subjects were present in this study. They had a fairly low ability to report on the existence of many aircraft, or accurately recall their location or many of their parameters. Their accuracy was significantly impacted by the number of aircraft present in the scenario and, to a lesser degree, by perceived workload.

Administrative Information

Investigator In Charge (IIC): Swick, Andrew

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John J Mecalo; Sabreliner; Perryville, MO
Brian Weber; Textron Aviation; Wichita, KS
Mark Morter; BAE Systems; Mojave, CA
Shane Terpstra; Plus One Flyers, Inc; La Jolla, CA
Grant Kowalchick; Navy-NAWCWD; NAS-Point Mugu, CA

Original Publish Date: November 15, 2016

Last Revision Date:

Investigation Class: [Class](#)

Note: The NTSB traveled to the scene of this accident.

Investigation Docket: <https://data.nts.gov/Docket?ProjectID=91793>

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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:	San Diego, California	Accident Number:	WPR15MA243
Date & Time:	August 16, 2015, 11:03 Local	Registration:	N442RM
Aircraft:	NORTH AMERICAN ROCKWELL NA265-60SC	Aircraft Damage:	Substantial
Defining Event:	Midair collision	Injuries:	4 Fatal
Flight Conducted Under:	Part 91: General aviation - Other work use		

Analysis

The Cessna 172 (N1285U) was conducting touch-and-go landings at Brown Field Municipal Airport (SDM), San Diego, California, and the experimental North American Rockwell NA265-60SC Sabreliner (N442RM, call sign Eagle1) was returning to SDM from a mission flight. SDM has two parallel runways, 8R/26L and 8L/26R; it is common in west operations for controllers to use a right traffic pattern for both runways 26R and 26L due to the proximity of Tijuana Airport, Tijuana, Mexico, to the south of SDM. On the morning of the accident, the air traffic control tower (ATCT) at SDM had both control positions (local and ground control) in the tower combined at the local control position, which was staffed by a local controller (LC)/controller-in-charge, who was conducting on-the-job training with a developmental controller (LC trainee). The LC trainee was transmitting control instructions for all operations; however, the LC was monitoring the LC trainee's actions and was responsible for all activity at that position.

About 13 minutes before the accident, the N1285U pilot contacted the ATCT and requested touch-and-go landings in the visual flight rules (VFR) traffic pattern. About that time, another Cessna 172 (N6ZP) and a helicopter (N8360R) were conducting operations in the VFR traffic pattern, and a Cessna 206 Stationair (N5058U) was inbound for landing. Over the next 5 minutes, traffic increased, with two additional aircraft inbound for landing. (Figure 1 in the factual report for this accident shows the aircraft in the SDM traffic pattern about 8 minutes before the accident.)

The LC trainee cleared the N1285U pilot for a touch-and-go on runway 26R; the pilot acknowledged the clearance and then advised the LC trainee that he was going to go around. The LC trainee advised the N1285U pilot to expect runway 26L on the next approach. At that time, three aircraft were using runway 26R (Global Express [N18WZ] was inbound for landing, N6ZP was on a right base for a touch-and-go, and a Cessna Citation [XALVV] was on short final) and three aircraft were using runway 26L (N1285U was turning right downwind for the touch-and-go, a Skybolt [N81962] was on a left downwind for

landing, and N8360R was conducting a touch-and-go landing). After N1285U completed the touch-and-go on runway 26L, the pilot entered a right downwind for runway 26R.

Meanwhile, Eagle1 was 9 miles west of the airport and requested a full-stop landing; the LC trainee instructed the Eagle1 flight crew to enter a right downwind for runway 26R at or above an altitude of 2,000 ft mean sea level. At this time, about 3 minutes before the accident, the qualified LC terminated the LC trainee's training and took over control of radio communications. From this time until the collision occurred, the LC was controlling nine aircraft. (Figure 2 and Figure 4 in the factual report for this accident show the total number of aircraft under ATCT control shortly before the accident.)

During the next 2 minutes, the LC made several errors. For example, after N6ZP completed a touch-and-go on runway 26R, the pilot requested a right downwind departure from the area, which the LC initially failed to acknowledge. The LC also instructed the N5058U pilot, who had been holding short of runway 26L, that he was cleared for takeoff from runway 26R. Both errors were corrected. In addition, the LC instructed the helicopter pilot to "listen up. turn crosswind" before correcting the instruction 4 seconds later to "turn base." (Figure 2 in the factual report for this accident shows the aircraft in the traffic pattern about 2 minutes before the accident.)

About 1 minute before the collision, the Eagle1 flight crew reported on downwind midfield and stated that they had traffic to the left and right in sight. At that time, N1285U was to Eagle1's right, between Eagle1 and the tower, and established on a right downwind about 500 ft below Eagle1's position. N6ZP was about 1 mile forward and to the left of Eagle1, heading northeast and departing the area. Mistakenly identifying the Cessna to the right of Eagle1 as N6ZP, the LC instructed the N6ZP pilot to make a right 360° turn to rejoin the downwind when, in fact, N1285U was the airplane to the right of Eagle1. (The LC stated in a postaccident interview that he thought the turn would resolve the conflict with Eagle1 and would help the Cessna avoid Eagle1's wake turbulence.) The N6ZP pilot acknowledged the LC's instruction and began turning; N1285U continued its approach to runway 26R.

However, the LC never visually confirmed that the Cessna to Eagle1's right (N1285U) was making the 360° turn. Ten seconds later, the LC instructed the Eagle1 flight crew to turn base and land on runway 26R, which put the accident airplanes on a collision course. The LC looked to ensure that Eagle1 was turning as instructed and noticed that the Cessna on the right downwind (which he still mistakenly identified as N6ZP) had not begun the 360° turn that he had issued. The LC called the N6ZP pilot, and the pilot responded that he was turning. In the first communication between the LC and the N1285U pilot (and the first between the controllers in the ATCT and that airplane's pilot in almost 6 minutes), the LC transmitted the call sign of N1285U, which the pilot acknowledged. N1285U and Eagle1 collided as the LC tried to verify N1285U's position.

A postaccident examination of both airplanes did not reveal any mechanical anomalies that would have prevented the airplanes from maneuvering to avoid an impact.

Local Controller Actions

In a postaccident interview, the LC stated that his personal limit for handling aircraft was four aircraft on runway 26R plus three aircraft on runway 26L (for a total of seven). From the time the LC took over local control communications from the LC trainee (3 minutes before the accident) until the time of the collision, the LC was in control of nine aircraft. Thus, the LC had exceeded his own stated workload

limit. Research indicates that the cognitive effects of increasing workload may include memory deficits; distraction; narrowing of attention; decreased situational awareness; and increased errors, such as readback errors or giving instructions to the wrong aircraft. (Mica Endsley and Mark Rodgers's 1997 report, *Distribution of Attention, Situation Awareness, and Workload in a Passive Air Traffic Control Task: Implications for Operational Errors and Automation* [FAA Report No. DOT/FAA/AM-97/13], details the cognitive effects of increasing workload.) To resolve the increasing workload, the LC had two options. He could have directed traffic away from SDM or split the local control/ground control positions, but he did neither. The LC trainee was qualified to work the ground control position, and the SDM ATCT had three controllers in the facility, which was the normal staffing schedule for that day and time.

As a result of the high workload, the LC made several errors after taking over the position from the LC trainee, including not responding promptly to a departure request from the N6ZP pilot and incorrectly instructing a helicopter pilot to turn to crosswind before correcting the instruction to turn base. The LC also did not provide traffic and/or sequence information with the instructions for the N6ZP pilot to turn 360° right. If the LC had done so, the N6ZP pilot might have reminded the controller that he was departing the airspace or requested clarification per 14 Code of Federal Regulations (CFR) 91.123(a), "Compliance with ATC [Air Traffic Control] Clearances and Instructions." In addition, if the Eagle1 flight crew had heard their aircraft called as traffic to another aircraft, it may have helped their visual search or prompted them to seek more information about the location of the conflicting traffic. The LC's stress amid the high workload was evidenced in his "listen up. turn crosswind" instruction to the helicopter pilot, after which the Eagle1 cockpit voice recorder (CVR) recorded the pilot comment, "wowwww. he's like panicking" (with an emphasis on "panicking").

Most importantly, the LC misidentified N1285U as N6ZP and did not ensure that the Cessna to the right of Eagle1 was performing the 360° turn before issuing the turn instruction to Eagle1. Although the N6ZP pilot had already requested a departure from the area and the LC had approved the departure request, the LC still believed that N6ZP was to the right of Eagle1, which indicates that the LC lacked a full and accurate mental model of the situation once he took over communications from the LC trainee. The LC trainee stated in a postaccident interview that when the Cessna on the right did not start the right turn, he suggested to the LC that the intended aircraft may have been N1285U. The high workload due to the increased traffic likely contributed to the LC's incomplete situational awareness.

In a postaccident interview, the LC reported that, at the time that he took over for the LC trainee, he had four issues to resolve, one of which was the potential conflict between Eagle1 and the Cessna on the right. Thus, he was aware of the potential conflict between two aircraft, even though he did not have the accurate mental picture of which Cessna was which. The LC explained that the acknowledgement from the N6ZP pilot of the right 360° turn to rejoin the downwind indicated to him that the intended Cessna pilot to Eagle1's right had received and acknowledged his instructions. Had he looked up to ensure that the control instructions that he provided to the Cessna on the right were being performed, he would have noticed that the Cessna to the right of Eagle1 was not turning and likely would not have issued the conflicting turn instruction to Eagle1.

Further, Federal Aviation Administration (FAA) Order 7110.65, paragraph 2-1-6, "Safety Alerts," states, in part, that a controller should "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..." About 14 seconds elapsed between the LC's base turn instruction and landing clearance for

Eagle1 and his call to the N6ZP pilot to ask about the right 360° turn instruction. When the LC saw that the airplanes were in unsafe proximity to each other, his priority should have been to separate the aircraft by issuing a safety alert to the Eagle1 flight crew (such as "TRAFFIC ALERT, Eagle1, to your right and below at pattern altitude, advise you climb immediately"). However, instead of issuing a safety alert to the Eagle1 flight crew, he separately called each Cessna pilot to verify their call signs and positions, which demonstrated narrowing of attention, another indication of the LC's stress due to high workload. If the LC had issued a safety alert to the Eagle1 flight crew as soon as he looked up after clearing Eagle1 to land and noticed that the Cessna to the right of Eagle1 was not turning, the Eagle1 pilots may have been able to take action to avoid N1285U. After the accident, on August 26, 2015, the SDM ATCT issued a Corrective Action Plan regarding inconsistencies in how controllers were issuing traffic advisories and safety alerts. The plan required controllers to review FAA Order 7110.65V, Air Traffic Control, paragraphs 2-1-6 and 2-1-21, as refresher training before working an operational position.

See-and-Avoid Concept

According to 14 CFR 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." 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 instrument flight rules 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.

A review of the ATCT and Eagle1 CVR transcripts revealed that during the entire time that the Eagle1 flight crew was on the ATCT local control frequency, there were no communications to or from N1285U. According to the CVR transcript, the Eagle1 pilots were aware of other traffic in the area and were actively looking for it; they had multiple airplanes in sight while on the downwind leg, and the pilot stated "I see the shadow but I don't see him" shortly before the accident. (Review of available data indicated that it was most likely the shadow of N1285U.)

Aircraft Performance and Cockpit Visibility Study

Our aircraft performance and cockpit visibility study determined that once Eagle1 began the turn to base leg, Eagle1 would have been largely obscured from the N1285U pilot's field of view but that N1285U should have remained in the Eagle1 pilots' field of view until about 4 seconds before the collision. (Figures 8a and 8b in the factual report for this accident show the simulated cockpit visibility from the Eagle1 copilot's seat and the N1285U pilot's seat at 1102:34, respectively.) Although the Eagle1 copilot would have had a better viewing position (in the right seat) to detect N1285U than the pilot, he was the pilot flying; thus, his attention would have been divided among multiple tasks, including configuring,

operating, and maneuvering the airplane for approach and landing, as well as scanning for traffic. (Throughout Eagle1's CVR recording, the pilot, seated in the left seat, was communicating on the radio and responding to checklists, consistent with that pilot acting as the pilot monitoring and the copilot, seated in the right seat, acting as the pilot flying.) N1285U's lack of relative motion in the Eagle1 pilots' field of view, combined with the fact that N1285U was below their horizon and, therefore, against the visual clutter of the background terrain, significantly decreased N1285U's visual conspicuity to the Eagle1 pilots.

It is likely that, as N1285U neared the end of the downwind leg (after Eagle1 overtook N1285U from behind and to the left), the pilot was anticipating his turn to the base leg and that his primary external visual scan was to the right, toward the airport, instead of to the left where Eagle1 was. Although the pilot may have had some cues of Eagle1's relative positioning in the pattern based on his monitoring of the ATCT communications, the challenge remained of detecting the airplane visually while maneuvering in the pattern.

Cockpit Display of Traffic Information

Although the N1285U and Eagle1 pilots were responsible for seeing and avoiding the other aircraft in the traffic pattern, our aircraft performance and cockpit visibility study revealed that their fields of view were limited and partially obscured at times. Research indicates that any mechanism to augment and focus a pilot's visual search 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. The accident airplanes were not equipped with these types of systems, but 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.)

While Eagle1 remained obscured from the N1285U pilot's field of view during Eagle1's downwind-to-base turn, N1285U remained in the Eagle1 (right seat) copilot's field of view for the majority of the 3 minutes preceding the accident. Even though both Eagle1 pilots were aware of and actively looking for traffic in the pattern, they still failed to see and avoid colliding with N1285U, which underscores the shortcomings in the see-and-avoid concept. An in-cockpit traffic display would have shown the Eagle1 pilots all of the traffic at the airport about the time of their initial call to the ATCT, and, about 2 minutes later, the Eagle1 pilots would have received an aural alert; the display would have shown N1285U's target change from a cyan color to a yellow color positioned between Eagle1 and the airport. About 1 1/2 minutes later, the Eagle1 pilots would have received another aural alert. The N1285U pilot would also have received an aural alert several seconds before impact, which may not have given him enough time to take evasive action. While most systems are limited to aiding pilots in their visual acquisition of a target and cannot provide resolution advisories (specific maneuvering instructions intended to avoid

the collision), a cockpit indication of traffic would likely have heightened the pilots' situational awareness and possibly alerted them of the need to change their flightpaths to resolve the conflict.

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 July 7, 2015, near Moncks Corner, South Carolina; 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.)

Probable Cause and Findings

The National Transportation Safety Board determines the probable cause(s) of this accident to be: The local controller's (LC) failure to properly identify the aircraft in the pattern and to ensure control instructions provided to the intended Cessna on downwind were being performed before turning Eagle1 into its path for landing. Contributing to the LC's actions was his incomplete situational awareness when he took over communications from the LC trainee due to the high workload at the time of the accident. Contributing to the accident were the inherent limitations of the see-and-avoid concept, resulting in the inability of the pilots involved to take evasive action in time to avert the collision.

Findings

Personnel issues	Attention - ATC personnel
Personnel issues	Accuracy of communication - ATC personnel
Personnel issues	Situational awareness - ATC personnel
Personnel issues	Task scheduling - ATC personnel
Personnel issues	Monitoring other aircraft - Pilot of other aircraft

Factual Information

History of Flight

Approach-VFR pattern base	Midair collision
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This report was modified on October 31, 2016. Please see the docket for this accident to view the original report.

On August 16, 2015, about 1103 Pacific daylight time, a Cessna 172M, N1285U, and an experimental North American Rockwell NA265-60SC Sabreliner, N442RM (call sign Eagle1), collided in midair about 1 mile northeast of Brown Field Municipal Airport (SDM), San Diego, California. The pilot (and sole occupant) of N1285U and the two pilots and two mission specialists aboard Eagle1 died; both airplanes were destroyed. N1285U was registered to a private individual and operated by Plus One Flyers under the provisions of 14 *Code of Federal Regulations (CFR)* Part 91 as a personal flight. Eagle1 was registered to and operated by BAE Systems Technology Solutions & Services, Inc., for the US Department of Defense as a public aircraft in support of the US Navy. No flight plan was filed for N1285U, which originated from Montgomery-Gibbs Executive Airport, San Diego, California. A mission flight plan was filed for Eagle1, which originated from SDM about 0830 and was returning to SDM. Visual meteorological conditions prevailed at the time of the accident.

On the morning of the accident, the SDM airport traffic control tower (ATCT) had all control positions (local and ground control) in the tower combined to the local control position. The position was staffed by a qualified local controller (LC)/controller-in-charge (CIC) who was conducting on-the-job training with a developmental controller (LC trainee) on the local control position. The LC trainee was transmitting control instructions for all operations; however, the qualified LC was closely monitoring the LC trainee's actions and was responsible for all activity at that position.

According to air traffic control (ATC) radar and voice communications data, the pilot of N1285U contacted the SDM ATCT at 1049:44 and requested touch-and-go maneuvers in the visual flight rules (VFR) traffic pattern. N1285U was inbound about 6 miles to the northeast of SDM, at an indicated altitude of 2,600 ft. About that time, another Cessna 172 (N6ZP) and a helicopter (N8360R) were conducting operations in the VFR traffic pattern, and a Cessna 206 Stationair (N5058U) was inbound for landing after carrying parachutists to a local drop zone about 5 nautical miles (nm) east of the field.

Between about 1049 and 1054, N6ZP and the helicopter continued to conduct approaches, N5058U landed on runway 26L, a Skybolt (N81962) reported west of SDM for landing on runway 26L, and a Cessna Citation (XALVV) reported straight in for landing on runway 26R. At 1052:57, the LC trainee cleared the pilot of N1285U for a touch-and-go on runway 26R, which the pilot acknowledged. At 1054:46, when N1285U was on final approach of the first approach to runway 26R, the pilot advised the LC trainee that he was going to go around. The LC trainee acknowledged the transmission and instructed the pilot to follow "a Cessna" (N6ZP) on the right downwind.

At 1056:31, the LC trainee advised the pilot of N1285U to expect runway 26L on the next approach,

which the pilot acknowledged. At that time, three aircraft were using runway 26R (Global Express [N18WZ] was inbound for landing, N6ZP was on a right base for a touch-and-go, and XALVV was on short final) and three aircraft were using runway 26L (N1285U was turning right downwind for the touch-and-go, N81962 was on a left downwind for landing, and N8360R was conducting a touch-and-go operation). Figure 1 shows the aircraft in the SDM traffic pattern about 8 minutes before the accident.



Figure 1. Aircraft in the SDM traffic pattern about 8 minutes before the accident.

At 1057:22, the LC trainee cleared the pilot of N1285U for a touch-and-go on runway 26L, and at 1057:27, the pilot acknowledged the clearance. At 1058:22, the LC trainee cleared the pilot of N6ZP for a touch-and-go on runway 26L. At 1058:29, the pilot of N6ZP stated, "...ah two six right cleared touch

and go." After the pilot of N1285U completed the touch-and-go on runway 26L, the pilot turned the airplane right, crossing through the departure corridor of runway 26R, and entered a right downwind for runway 26R.

At 1059:04, when Eagle1 was 9 miles west of SDM, the flight crew contacted the SDM ATCT and requested a full-stop landing. Throughout Eagle1's cockpit voice recorder (CVR) recording, the pilot, seated in the left seat, was communicating on the radio and responding to checklists, consistent with that pilot acting as the pilot monitoring and the copilot, seated in the right seat, acting as the pilot flying. The LC trainee instructed the Eagle1 flight crew to enter a right downwind for runway 26R at or above an altitude of 2,000 ft mean sea level (msl).

At 1059:18, the pilot of N5058U reported holding short of runway 26L on taxiway C. (N5058U had landed on runway 26L at 1052:30 and was returning to runway 26L for takeoff.) The LC trainee mistakenly advised the pilot of N5058U to hold short of runway 26R. The pilot of N5058U clarified that he was holding short of 26L, and, at 1059:31, the LC trainee acknowledged the transmission. That was the last transmission from the LC trainee. At 1059:33, the qualified LC terminated the LC trainee's training and took over control of communications due to increased traffic. The LC trainee signed off the position but remained in the tower to observe operations. From this time until the collision occurred (about 1103), the LC was controlling nine aircraft.

During the next 2 minutes, the LC made several errors that were either corrected by him or by the pilots under his control. At 1059:44, after the pilot of N6ZP completed a touch-and-go on runway 26R, he requested a right downwind departure from the area. The LC did not respond. At 1100:23, the LC instructed, "stationair five eight uniform two six right cleared for I'm sorry two six left cleared for takeoff." At 1100:29, the pilot of N5058U stated, "uh I'm sorry was that for five eight uniform?" The LC then cleared the pilot of N5058U for takeoff from runway 26L. At 1100:36, the LC transmitted, "helicopter six zero romeo there is a ces ah cen ah correction stationair just ahead they are going to the right runway base leg for two six left." At 1100:46, the pilot of N6ZP repeated his request for departure; the LC then approved N6ZP's departure request, and N6ZP departed the traffic pattern in a northeasterly direction. At 1100:53, the LC instructed the helicopter pilot, "helicopter six zero romeo listen up turn crosswind" before correcting the instruction 4 seconds later to "turn base." At 1101:15, the Eagle1 CVR recorded the copilot state, "got one on the runway," and at 1101:19, the Eagle1 CVR recorded the pilot comment, "wowww. he's like panicking" (with an emphasis on panicking). Figure 2 shows the aircraft in the SDM traffic pattern from about 1101 until the time of the accident.

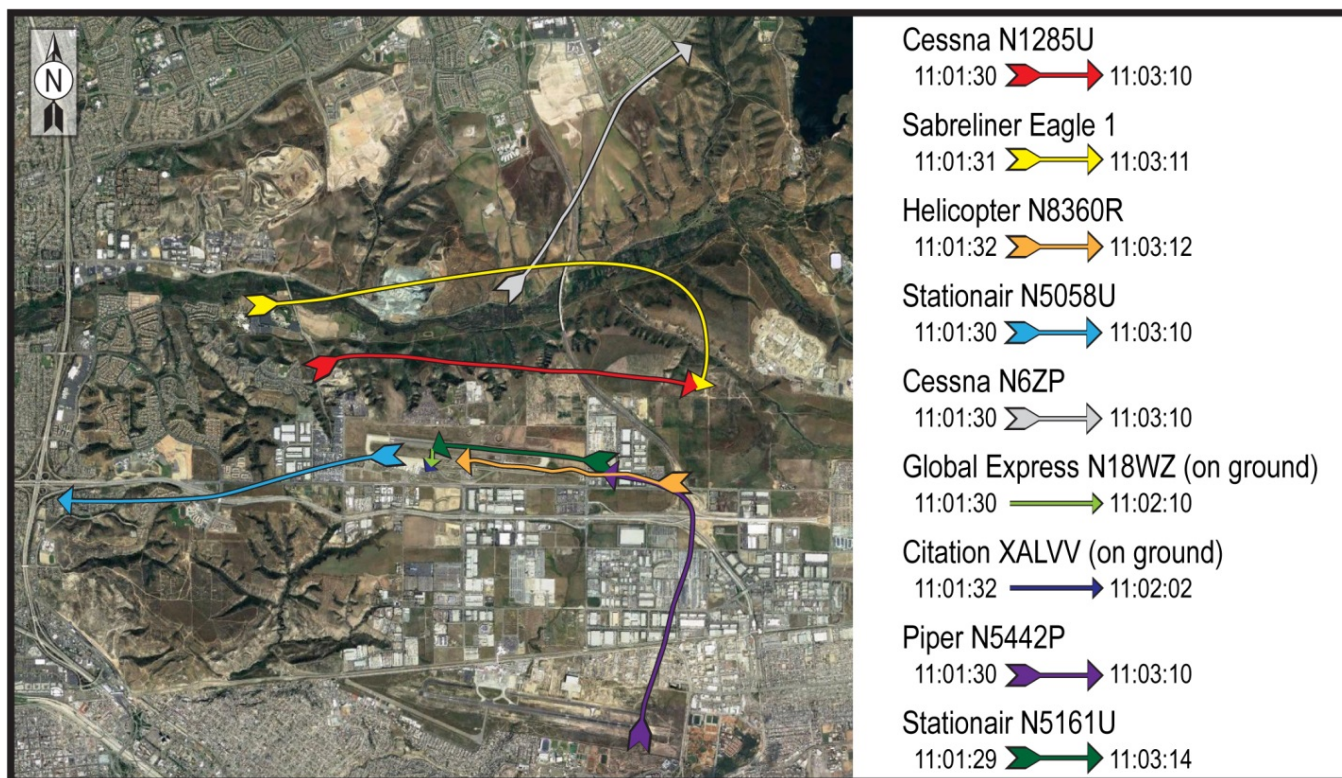


Figure 2. Aircraft in the SDM traffic pattern from about 1101 until the time of the accident.

At 1101:49, the Eagle1 CVR recorded one of the mission specialists seated outside the cockpit ask "see him right there?" At 1102:14, while on the right downwind leg (and, according to radar data, while overtaking N1285U from behind and to the left) and abeam the tower, the Eagle1 flight crew reported to the ATCT that they had traffic in sight to the left and the right of their position. Radar data indicated that N6ZP was to the left of Eagle1 and heading to the northeast, and N1285U was between Eagle1 and SDM, on a closer-in right downwind leg.

At 1102:32, the LC instructed the pilot of N6ZP, which he thought was the Cessna on right downwind, to make a right 360° turn over the airport and rejoin the downwind. Despite the fact that, at that time, N6ZP was 2.3 nm northeast of the airport and was departing the area, the pilot of N6ZP acknowledged the instruction and initiated a right turn. At the same time, Eagle1's CVR recorded the pilot asking, "you still got the guy on the right side?"

At 1102:42, the LC instructed the Eagle1 flight crew to turn base and cleared the flight to land on runway 26R. The LC stated in the postaccident interview that after he cleared the Eagle1 flight crew to land, he looked up to ensure that Eagle1 was turning base and noticed that the Cessna on downwind (which he still thought was N6ZP) was continuing on its downwind track and had not begun the turn that

he had issued. At 1102:56, the LC contacted the pilot of N6ZP, and the N6ZP pilot replied by stating that he was turning. At 1102:59, Eagle1's CVR recorded the pilot comment "I see the shadow but I don't see him."

At 1103:04, the LC transmitted "November eight five uniform"; this was the first ATC transmission with N1285U in almost 6 minutes and the first communication between the LC and N1285U. At 1103:07, the pilot of N1285U acknowledged the transmission, "eight five uniform." At 1103:08, the LC asked the pilot of N1285U if he was still on the right downwind leg. The pilot of N1285U did not respond. The LC and the LC trainee then witnessed Eagle1 and N1285U collide.

Two witnesses located on the ramp at SDM saw the two airplanes flying eastbound, to the north of SDM. The witnesses turned away momentarily, and as they turned back, they saw an explosion, followed by airplane fragments falling to the ground. Another witness located about 2 miles east-northeast of SDM saw both airplanes at the same altitude, on intersecting flightpaths. That witness reported that the smaller airplane was flying away from the airport and that the larger airplane was flying toward the airport and descending. He noted that neither airplane appeared to make any corrective action before the collision and stated that after the collision, the smaller airplane broke apart, while the larger airplane lost a wing, nosed down, and impacted the ground.

The LC stated in a postaccident interview that the traffic level was "light and not complex" at the beginning of the training session. He stated that he noticed the traffic volume and complexity became "moderate" when the LC trainee was under instruction, which prompted the LC to terminate training and take over communications. He reported that, at that time, he had four issues to resolve, one of which was the potential conflict between Eagle1 and the Cessna on the right. He indicated that he saw Eagle1 on a midfield right downwind leg when the pilot of Eagle1 reported that he was "abeam and had the traffic to the left and right in sight." The LC stated that, at that time, Eagle1 was flanked by two Cessnas. Although the Cessna on the right of Eagle1 was N1285U, the LC believed that the Cessna on the close-in right downwind was N6ZP; therefore, he instructed the pilot of N6ZP to make a right 360° turn to rejoin the midfield downwind. He stated that he felt the turn would resolve the conflict with Eagle1 and that the right turn would help the Cessna avoid Eagle1's wake turbulence. When the pilot of N6ZP acknowledged the turn, the LC believed that the pilot of the Cessna to the right of Eagle1 had received the instructions and that the potential conflict with Eagle1 would be resolved. The LC then instructed Eagle1 to turn base and cleared the flight crew to land on runway 26R.

The LC stated that after he cleared the Eagle1 flight crew to land, he looked up to ensure that Eagle1 was turning as instructed. When the LC noticed that the Cessna to the right of Eagle1 had not started the right 360° turn, he began to query the pilot of N6ZP and then the pilot of N1285U. At that point, he witnessed the collision.

The LC also indicated in the postaccident interview that controllers have personal limits about how many airplanes they could handle and that he could handle four aircraft on runway 26R and three aircraft on runway 26L. When the LC was asked what caused him to realize that the Cessna was N1285U and not N6ZP, he said it dawned on him that he had a right downwind departure, and through the process of elimination, it could not have been anyone else. The LC trainee stated in a postaccident interview that when the Cessna on the right did not start the right turn, he suggested to the LC that the intended aircraft may have been N1285U. The LC indicated that, in retrospect, he should have issued a

traffic alert; however, the moment he realized that Eagle1 was turning into N1285U, it was too late to help. Figure 3 shows the calculated flight tracks of Eagle1 and N1285U. Figure 4 shows the aircraft under SDM ATCT control from 1049 until the time of the collision.



Figure 3. Calculated flight tracks of Eagle1 and N1285U.

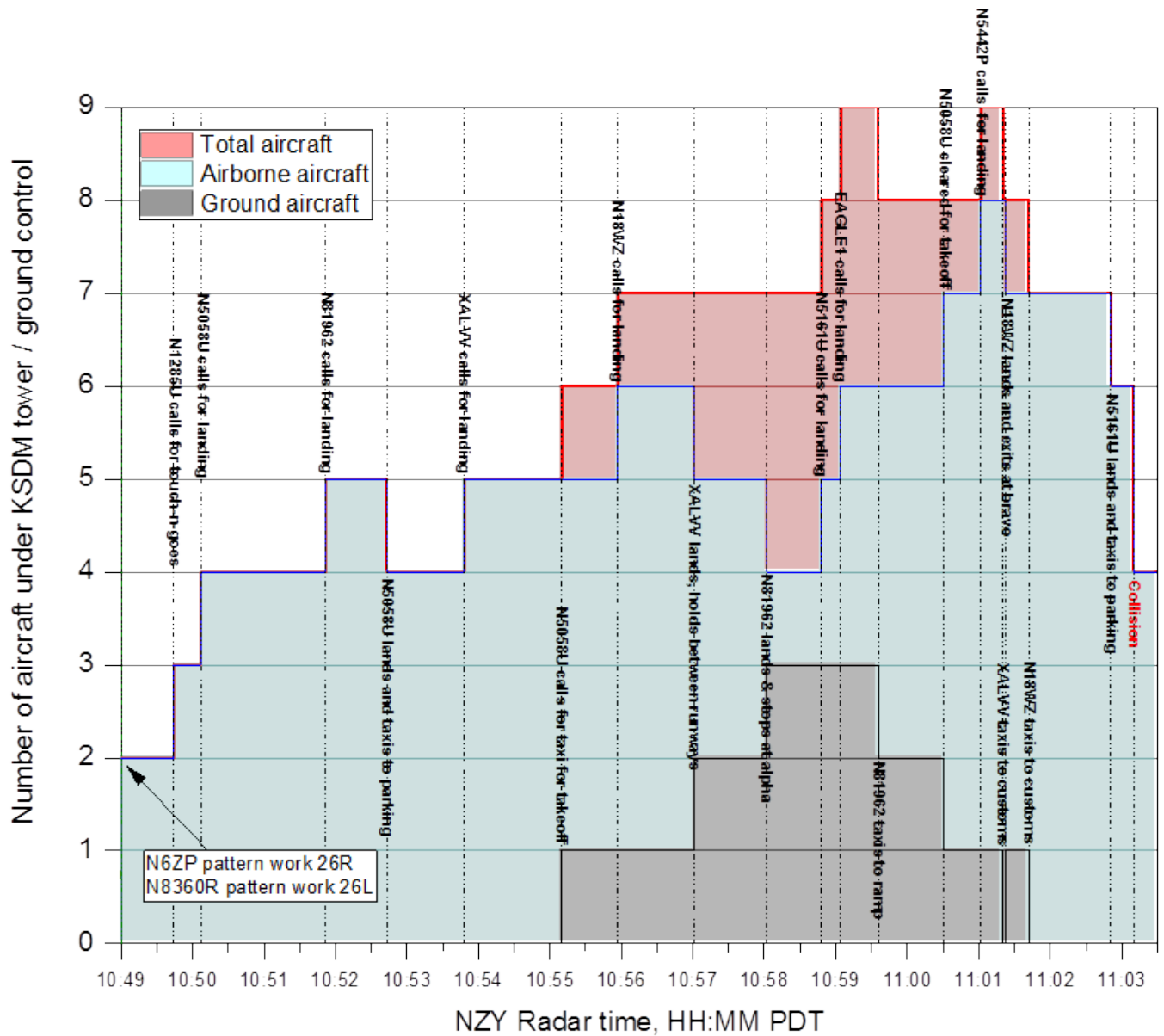


Figure 4. Total aircraft under SDM ATCT control from 1049 until the time of the collision.

Pilot Information

Certificate:	Airline transport; Flight instructor	Age:	41
Airplane Rating(s):	Single-engine land; Multi-engine land	Seat Occupied:	Left
Other Aircraft Rating(s):	Glider	Restraint Used:	5-point
Instrument Rating(s):	Airplane	Second Pilot Present:	Yes
Instructor Rating(s):	Airplane multi-engine; Airplane single-engine; Glider; Instrument airplane	Toxicology Performed:	No
Medical Certification:	Class 1 Without waivers/limitations	Last FAA Medical Exam:	April 20, 2015
Occupational Pilot:	Yes	Last Flight Review or Equivalent:	April 13, 2015
Flight Time:	4485 hours (Total, all aircraft), 347 hours (Total, this make and model), 3861 hours (Pilot In Command, all aircraft), 18 hours (Last 90 days, all aircraft), 18.2 hours (Last 30 days, all aircraft), 3 hours (Last 24 hours, all aircraft)		

Co-pilot Information

Certificate:	Airline transport; Commercial	Age:	66, Male
Airplane Rating(s):	Single-engine land; Multi-engine land	Seat Occupied:	Right
Other Aircraft Rating(s):	None	Restraint Used:	5-point
Instrument Rating(s):	Airplane	Second Pilot Present:	Yes
Instructor Rating(s):	None	Toxicology Performed:	No
Medical Certification:	Class 1 With waivers/limitations	Last FAA Medical Exam:	January 12, 2015
Occupational Pilot:	Yes	Last Flight Review or Equivalent:	December 13, 2013
Flight Time:	6400 hours (Total, all aircraft), 3307 hours (Pilot In Command, all aircraft)		

N1285U Pilot

The pilot, age 60, held a private pilot certificate for airplane single-engine land issued on December 2, 1997. His most recent Federal Aviation Administration (FAA) third-class medical certificate was issued on November 20, 2014, with limitations stating that he must wear corrective lenses for near and distant vision. The pilot's logbooks revealed that he had accumulated about 277 total flight hours, including 9.7 hours in the last 6 months.

Eagle1 Pilot (Pilot Monitoring)

The pilot, age 41, held an airline transport pilot certificate issued on April 1, 2011, and a flight instructor certificate issued on November 8, 2008 (most recent renewal on November 25, 2014). He held instructor ratings for airplane multiengine, single-engine, single-engine instrument, and glider. His most recent FAA first-class medical certificate was issued on April 30, 2015, with no limitations. According to BAE, the pilot had about 4,480 total flight hours. In the 90 days before the accident, he logged 18 hours

in airplanes, including 4 hours in the accident airplane make and model. His most recent flight review was completed on April 13, 2015. The pilot was seated in the left seat and was acting as the pilot monitoring.

Eagle1 Copilot (Pilot Flying)

The copilot, age 66, held an airline transport pilot certificate issued on March 8, 2005, and a flight instructor certificate issued on October 20, 2009. The copilot held ratings for airplane multiengine and single-engine land. His most recent FAA first-class medical certificate was issued on January 12, 2015, with the limitation that he must wear corrective lenses. According to BAE, the copilot had about 7,150 total flight hours, and his most recent flight review was completed on April 13, 2015. The copilot was seated in the right seat and was acting as the pilot flying.

Local Controller/Controller-in-Charge

The local controller at the time of the accident, age 59, was a certified professional controller and CIC. He had 37 years of ATC experience: 5 years in the US Air Force, 24 years with the FAA, and 8 years with his current employer. He was qualified on all positions in the SDM ATCT on September 18, 2014, and was certified as an SDM CIC on September 19, 2014. He was designated as an on-the-job training instructor on February 10, 2015. His most recent recurrent training was completed on July 31, 2015, and included, but was not limited to, the topics of runway separation, visual separation, limited aviation weather reporting station (LAWRS), and opposite direction operations. His most recent FAA second-class medical certificate was issued on September 23, 2014, with the limitation that he must wear corrective lenses. He indicated in a postaccident interview that he was in compliance with the limitation at the time of the accident.

Local Control Trainee

The LC trainee, age 27, was qualified on ground and flight data control positions on June 25, 2015. He completed local controller classroom training on June 22, 2015, and started on-the-job training on the local control position on June 27, 2015. His most recent recurrent training was completed on July 31, 2015, and included, but was not limited to, the topics of runway separation, visual separation, LAWRS, and opposite direction operations. His most recent FAA second-class medical certificate was issued on April 28, 2015, with no limitations.

Aircraft and Owner/Operator Information

Aircraft Make:	NORTH AMERICAN ROCKWELL	Registration:	N442RM
Model/Series:	NA265-60SC 60	Aircraft Category:	Airplane
Year of Manufacture:	1974	Amateur Built:	
Airworthiness Certificate:	Experimental (Special)	Serial Number:	306-073
Landing Gear Type:	Retractable - Tricycle	Seats:	5
Date/Type of Last Inspection:	July 20, 2015	Certified Max Gross Wt.:	22900 lbs
Time Since Last Inspection:		Engines:	2 Turbo jet
Airframe Total Time:	13418.1 Hrs as of last inspection	Engine Manufacturer:	P & W
ELT:	C91A installed, not activated	Engine Model/Series:	JT12A-8
Registered Owner:	BAE SYSTEMS TECHNOLOGY SOLUTIONS & SERVI	Rated Power:	3300 Horsepower
Operator:	BAE SYSTEMS TECHNOLOGY SOLUTIONS & SERVI	Operating Certificate(s) Held:	None

N1285U Airplane

The white- and yellow-colored Cessna 172M was a high-wing, four-seat airplane manufactured in 1976 and powered by a Lycoming O-320-D2G engine rated at 160 horsepower, installed under RAM Aircraft Modifications supplemental type certificate SA2375SW. The airplane had a gross weight of 2,300 lbs. The most recent annual inspection was conducted on July 15, 2015. At the time of inspection, the airplane had a total time of 9,848.1 flight hours. It was equipped with a rotating beacon light, anticollision strobe lights, navigation position lights, a landing light, and a taxi light. The operational status of each lighting system at the time of the accident could not be determined. N1285U 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.

Eagle1

The white-colored North American Rockwell NA265-60SC Sabreliner was a low-wing, five-seat airplane manufactured in 1974 and powered by two Pratt and Whitney JT12A-8 turbojet engines, each rated at 3,000 lbs of thrust. The accident airplane was operating with an experimental airworthiness certificate because it had been modified with an external test pod attached to the lower side of the airplane aft of the nose landing gear. The airplane had a maximum gross weight of 22,900 lbs. According to the maintenance records, the most recent annual inspection was conducted on July 20, 2015. At the time of inspection, the airplane had a total time of 13,418 flight hours. The Sabreliner was equipped with a Fairchild GA-100 CVR with 30 minutes of analog audio on a continuous loop tape in a four-channel format. It was equipped with anticollision lights on the vertical tail and under the fuselage just forward of the main wheel well, wing ice inspection lights, strobe and position lights on the tail cone and each wing tip, and landing-taxi lights forward of the nose landing gear. The operational status of

each lighting system at the time of the accident could not be determined. The Sabreliner was not equipped with a TAS, TCAS, or ADS-B equipment or displays.

Meteorological Information and Flight Plan

Conditions at Accident Site:	Visual (VMC)	Condition of Light:	Day
Observation Facility, Elevation:	KSDM, 515 ft msl	Distance from Accident Site:	1 Nautical Miles
Observation Time:	17:53 Local	Direction from Accident Site:	250°
Lowest Cloud Condition:	Clear	Visibility	10 miles
Lowest Ceiling:	None	Visibility (RVR):	
Wind Speed/Gusts:	6 knots / None	Turbulence Type Forecast/Actual:	/
Wind Direction:	310°	Turbulence Severity Forecast/Actual:	/
Altimeter Setting:	29.87 inches Hg	Temperature/Dew Point:	33°C / 19°C
Precipitation and Obscuration:	No Obscuration; No Precipitation		
Departure Point:	San Diego, CA (KSDM)	Type of Flight Plan Filed:	Unknown
Destination:	San Diego, CA (KSDM)	Type of Clearance:	VFR
Departure Time:	08:30 Local	Type of Airspace:	Class D

The 1053 SDM automated weather observation included wind from 310°; at 6 knots, visibility 10 statute miles, clear skies, temperature 33° C, dew point 19° C, and an altimeter setting of 29.87 inches of mercury.

Airport Information

Airport:	BROWN FIELD MUNI SDM	Runway Surface Type:	Asphalt
Airport Elevation:	526 ft msl	Runway Surface Condition:	Dry
Runway Used:	26L	IFR Approach:	None
Runway Length/Width:	3180 ft / 75 ft	VFR Approach/Landing:	Traffic pattern

SDM is located about 14 nm southeast of San Diego on the Otay Mesa at an elevation of 526 ft msl. The rising terrain associated with the Otay Mountain peaks begins about 2 miles east-northeast of SDM, and the highest terrain, at an elevation of 3,566 ft msl, is located about 8 miles east of SDM. Designated skydiving areas are located at SDM and at a second location about 3 miles east of SDM (see figure 5).

SDM has two parallel runways. Runway 8L/26R measures about 7,972 ft long and 150 ft wide, and runway 8R/26L measures about 3,180 ft long and 75 ft wide. Although the published traffic pattern for 26R is right traffic, it is common in west operations for controllers to use a right traffic pattern for both runways 26R and 26L due to the proximity of Tijuana Airport, Tijuana, Mexico, to the south of SDM. Some helicopter traffic is assigned to use a left traffic pattern for runways 26L and 26R. The published

VFR pattern altitude at SDM is 1,526 ft for runway 8L/26R and 1,126 ft for runway 8R/26L. SDM operates within class D airspace, which includes the airspace extending upward from the surface to and including 3,000 ft msl within a 2.6-mile radius of SDM. (These dimensions are nonstandard; the normal radius is around 5 miles.)

The SDM ATCT is a nonapproach control federal contract tower, operated and staffed by a private company. Local controllers at nonapproach control towers must devote the majority of their time to visually scanning the runways and local area. The SDM ATCT employed five controllers; at the time of the accident, the ATCT was operating and had three controllers in the facility, which was the normal staffing schedule for that day and time. Both accident airplanes were operating under VFR in the class D airspace and were communicating with and being provided ATC services by SDM ATCT personnel. After the accident, on August 26, 2015, the SDM ATCT issued a corrective action plan regarding inconsistencies in how controllers were issuing traffic advisories and safety alerts. The plan required controllers to review FAA JO 7110.65V, *Air Traffic Control*, paragraphs 2-1-6 and 2-1-21, as refresher training before working an operational position.



Figure 5. FAA sectional aeronautical chart view depicting SDM and the approximate accident location. (Not for navigational use.)

Wreckage and Impact Information

Crew Injuries:	4 Fatal	Aircraft Damage:	Substantial
Passenger Injuries:		Aircraft Fire:	Both in-flight and on-ground
Ground Injuries:	N/A	Aircraft Explosion:	Both in-flight and on-ground
Total Injuries:	4 Fatal	Latitude, Longitude:	32.577499,-116.94889(est)

The wreckage was located in a large open area about 1 1/2 miles northeast of SDM and consisted of two primary debris fields, one for each airplane.

N1285U Airplane

N1285U's debris field, which was about 1,200 ft long and aligned on a magnetic heading of 055°, contained some components and fragments from Eagle1 and was located about 400 ft northeast of the Eagle1 debris field. The N1285U main wreckage contained the engine, propeller, and part of the main cabin. The main cabin wreckage consisted of parts of the floor, seats, and cabin structure. The engine remained partially attached to the firewall and exhibited impact damage to its left side, revealing cylinder components. The propeller assembly was found separated from the engine and partially buried in a small crater. The propeller was heavily gouged in multiple directions, and one blade had aft bending.

The left wing remained attached to a portion of the cabin roof and came to rest inverted. The wing and roof section had thermal damage. The flap and aileron remained attached to the wing. The inboard portion of the leading edge of the left wing displayed impact damage and red transfer marks. The fuselage and right wing were highly fragmented and spread throughout the debris field.

Eagle1

Most of the Eagle1 wreckage was contained within a radius of about 100 ft; no parts from N1285U were located within that radius. The Eagle1 main wreckage was on a magnetic heading of 060° and consisted of the cabin area, left wing, empennage, both engines, and the externally mounted test pod. The forward cabin area came to rest on its upper left side and was crushed. The remaining cabin area was crushed and had thermal damage. The left wing came to rest on its trailing edge, supported at an angle by the landing gear. Both engines were found near the tail section and displayed crush damage. The test pod and internal equipment had impact and thermal damage.

The Eagle1 right wing was found on a road near the N1285U debris field, about 400 ft north of the Eagle1 main wreckage. A power transmission line near the wing's location was separated during the accident. The wing displayed leading-edge damage from near the tip to the separation point from the inboard portion of the wing. About 4 ft of the inboard wing was separated and recovered with the main wreckage. A 5-ft section of leading edge, from the stall fence inboard, displayed leading-edge damage revealing the internal surfaces of the wing. The lower surface of the wing displayed metallic impact marks and paint transfer marks.

Follow-up Examination

Detailed examination of the wreckage from both airplanes was conducted at a secure facility several days after the accident. The right wing of Eagle1 was positioned with the N1285U wreckage, and investigators conducted an examination for contact evidence between the airplanes. The Eagle1 right wing had impact marks consistent with the impact of N1285U's engine. Specifically, the spacing of the impact marks on the inboard lower surface of the Eagle1 right wing were consistent with the spacing of the N1285U engine crankcase upper studs, flanges, and engine lifting eye. The angle of the marks relative to the Eagle1's longitudinal axis was about 30° and indicates that this was the convergence angle between the airplanes. The damage on the N1285U crankcase upper studs, flanges, and engine lifting eye was consistent with impact from its left side and with the computed convergence angle.

In addition, the conformity of the Cessna fuselage, wing strut, and wing spar damage to the Eagle1 wing shape indicates that the Eagle1 right wing impacted the left side of the Cessna. The evidence is consistent with the longitudinal axes of the two airplanes being approximately perpendicular to one another at the time of impact, with Eagle1 approaching the Cessna from the left, and with the Eagle1 right wing below the Cessna left wing.

The reconstruction of the airplanes' flightpaths, based on radar data, is described in the NTSB's Aircraft Performance and Cockpit Visibility Study for this accident. The collision geometry resulting from the trajectory reconstruction is consistent with the collision geometry indicated by the wreckage examination.

Flight recorders

Cockpit Voice Recorder

The CVR was recovered from the Eagle1 wreckage and forwarded to the National Transportation Safety Board (NTSB) vehicle recorders laboratory in Washington, DC, for readout. The CVR had 30 minutes of analog audio on a continuous loop tape in a four-channel format: one channel for each of the two pilot stations, one channel for the cockpit observer station, and one channel for the cockpit area microphone (CAM). The magnetic tape was retrieved from within the crash-protected case and was successfully downloaded.

The quality of the CVR audio information was degraded due to the erase mechanism not completely erasing the previous recordings, especially on the CAM channel. Timing on the transcript was established by correlating the CVR events to the common events recorded by SDM ATC. The CVR recording started at 1032:28 and ended at 1103:10. Due to the poor quality of the CVR recording, the SDM ATC transcript was used in conjunction with the CVR recording to clarify the flight crew's radio transmissions.

Medical and Pathological Information

The FAA's Civil Aerospace Medical Institute performed toxicology testing on tissue specimens from the three pilots. The specimens tested negative for ethanol and major drugs of abuse.

The LC and LC trainee on duty at the time of the accident tested negative for drugs and alcohol.

Tests and Research

Aircraft Performance and Cockpit Visibility Study

The NTSB's investigation examined the ability of the N1285U and Eagle1 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. Position and orientation information for both airplanes was estimated based on an analysis of the radar data, combined with models of each airplane's aerodynamic performance. For this study, the relative positions of the two aircraft were calculated beginning at 1100:06.0 and then at 0.05-second intervals up to the collision, which occurred at 1103:10.2. The time, location, and altitude of the collision were determined based on extrapolation of the radar data, the wreckage locations of both aircraft, and the time of the end of Eagle1's CVR recording. The locations of the structures and transparencies of Eagle1 in its copilot's (right seat) field of view, and of N1285U in its pilot's (left seat) field 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 study assumed a nominal pilot seating (and eye) position in each cockpit and evaluated a matrix of eye displacements from the nominal eye position. The variations in eye position indicated that pilot head movements can move the target airplane's position in the field of view into and out of areas that are obscured from the pilots. For Eagle1, the visibility of N1285U from the copilot's seat is sensitive to the pilot's eye position relative to the top and left edges of the Eagle1 R2 window, and for N1285U, the visibility of Eagle1 is sensitive to the pilot's eye position relative to the post between the left door window and the windshield (see figure 6 for a top-down view of the Eagle1 forward fuselage with cockpit windows labeled). The description of the visibility from each aircraft that follows is based on the pilots' eyes at "nominal" positions, determined by the eye positions of persons of similar stature to the accident pilots seated in exemplar airplanes. The Aircraft Performance and Cockpit Visibility Study for this accident describes how the visibility from each airplane changes with variation in eye position and notes that head movements in several directions while scanning for traffic can make otherwise obscured aircraft visible.

Eagle1's 10 cockpit windows (5 on each side of the airplane) are labeled L1 through L5 for the left

windows and R1 through R5 for the right windows, as shown in figure 6. The Cessna windows are the windshield, left window, and right window.

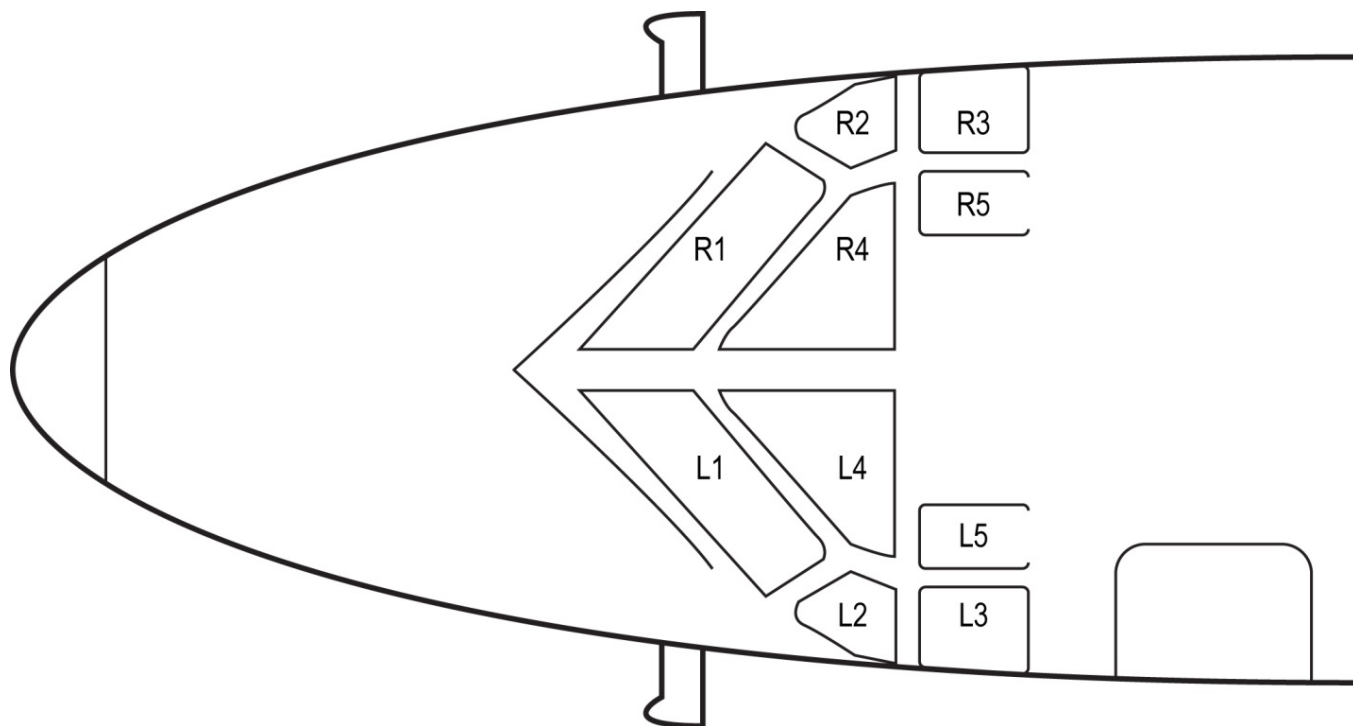


Figure 6. Top-down view of Eagle1 forward fuselage, showing labels used to identify cockpit windows.

At 1100:06, N1285U was climbing through 540 ft over runway 26L after completing its touch-and-go operation, and Eagle1 was 6 nm west and 1 nm north of the SDM runway 26R threshold, descending through 2,380 ft.

At 1100:29, Eagle1's CVR recorded the copilot comment "got one on short final" (likely Global Express N18WZ), and Eagle1 was descending through 2,260 ft, 1 nm north and 4.9 nm west of the runway 26R threshold. N1285U was climbing through 780 ft, along the extended centerline of runway 26L, and about 800 ft past the departure end of that runway. N1285U would have been located in Eagle1's R1 window. The other aircraft in the pattern would have been located in roughly the same area, except for the other Cessna 172, N6ZP, which was to the left in the R1 window. Eagle1 would have appeared in N1285U's windshield. The aircraft were 4.1 nm apart.

At 1100:55, N1285U was climbing through 1,150 ft about 1,200 ft west of the departure end of runway 26R and began a right turn to cross over the extended centerline of 26R to enter the right traffic pattern for that runway. Eagle1 was at 2,190 ft, about 1 nm north and 3.6 nm west of the runway 26R threshold, about 2.4 nm from N1285U, and would have been located in N1285U's windshield about in line with the top of the instrument panel. N1285U would have been located in Eagle1's R1 window.

At 1101:15.5, Eagle1's CVR recorded the copilot state "got one on the runway" (likely N18WZ). At this

time, N18WZ may have been obscured behind the post separating Eagle1's R1 and R2 windows, if the copilot's eyes had been looking from the "nominal" position. Since the copilot saw and commented on N18WZ, however, he may have been leaning closer to the window to scan for traffic, bringing N18WZ more into view. N1285U would have appeared in Eagle1's R2 window and was 1.2 nm away. Eagle1 would have appeared in the N1285U pilot's field of view near the forward edge of the post separating the left window from the windshield.

At 1101:24.6, Eagle1 was level at 2,100 ft, about 1 nm north and 2.4 nm west of the runway 26R threshold, when the pilot stated "I got twelve o'clock on a climb out." At this time, the Cessna 206 (N5058U) had recently departed from runway 26L. N1285U was 0.8 nm from Eagle1, climbing through 1,600 ft and turning from crosswind to right downwind for runway 26R, 0.5 nm north and 1.7 nm west of the runway 26R threshold. N1285U would have appeared in Eagle1's R2 window; N5058U would have appeared slightly below and to the left of N1285U. Eagle1 would have been hidden from the N1285U pilot's view behind the window post between the left window and windshield.

At 1101:43.1, N1285U would have been located just to the left of the window post separating Eagle1's R2 and R3 windows, and N5058U would have been just to the right of this post (see figure 7a). Eagle1 would have appeared in the left window of N1285U, just below the wingtip (see figure 7b). Eagle1 and N1285U were both on the right downwind leg for runway 26R, with Eagle1 about 0.4 nm north of N1285U.

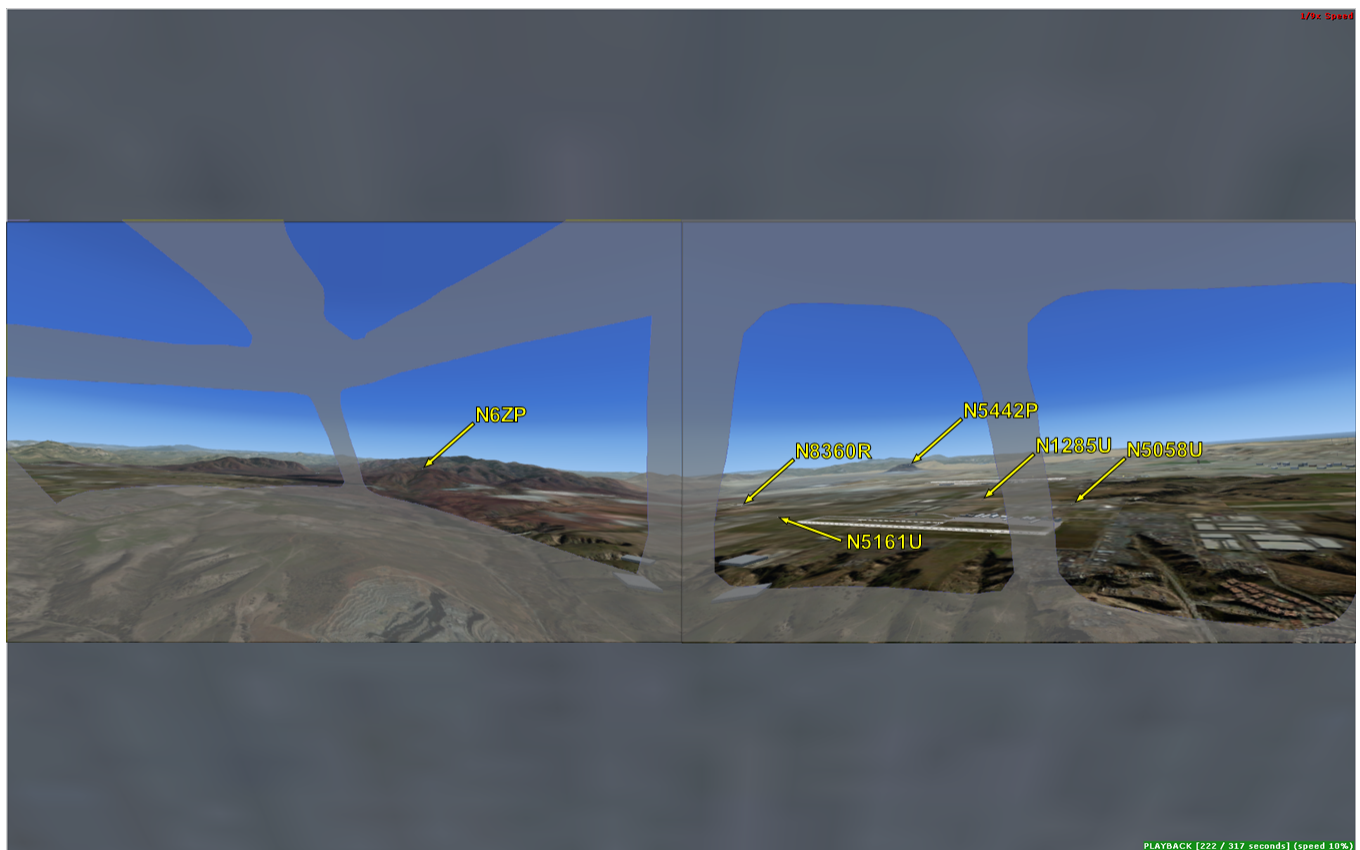


Figure 7a. View from the copilot seat of Eagle1 at 1101:43.1, when the airplanes were 0.5 nm apart.

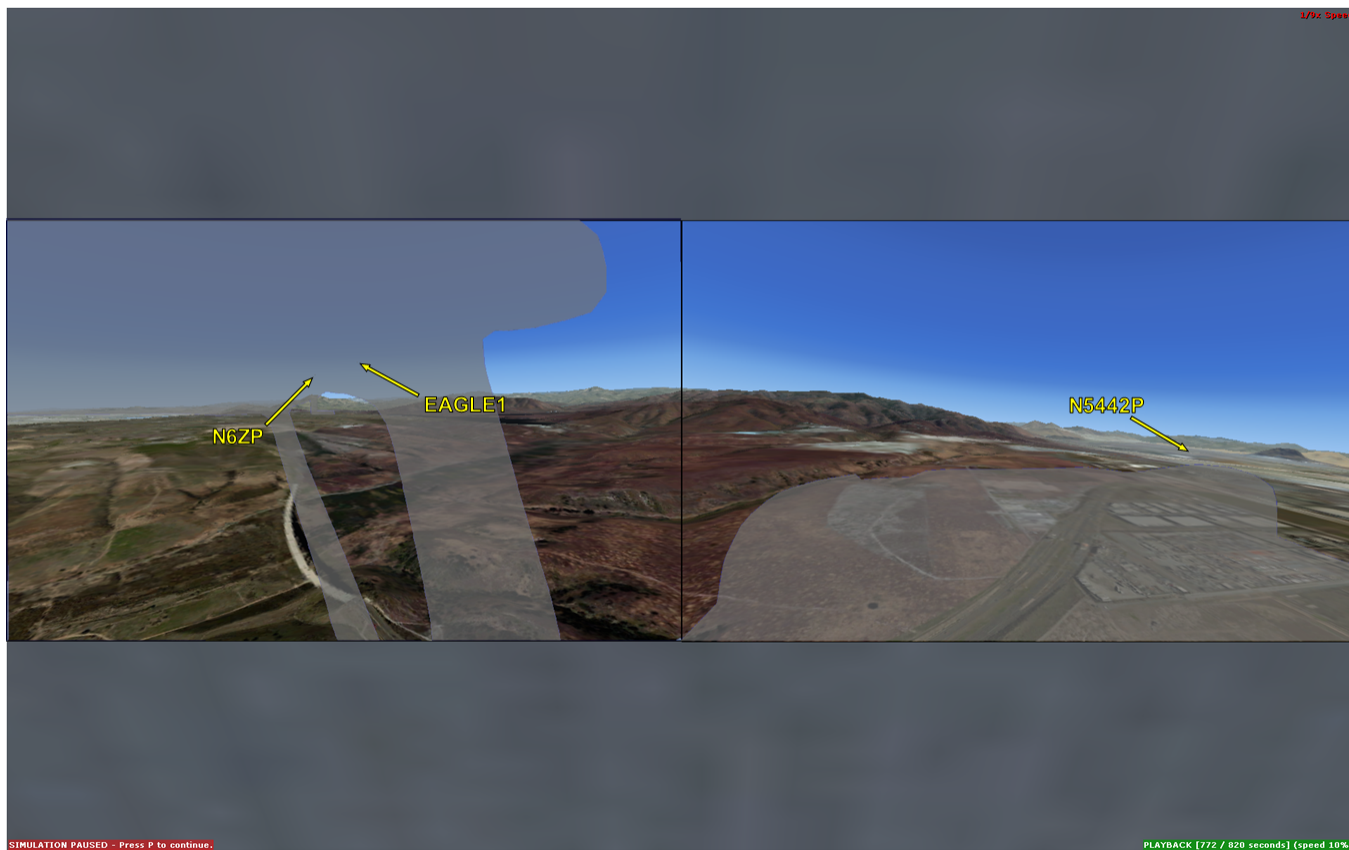


Figure 7b. View from the pilot seat of N1285U at 1101:43.1, when the airplanes were 0.5 nm apart.

At 1101:49.0, Eagle1's CVR recorded one of the mission specialists seated outside of the cockpit ask "see him right there?" Eagle1 was at about 2,040 ft, 1.1 nm north and 1.4 nm west of the runway 26R threshold. N1285U was level at 1,700 ft, 0.7 nm north and 1.3 nm west of the threshold. The airplanes were about 0.5 nm apart, and N1285U would have appeared in Eagle1's R3 window near the right edge of the post separating the R2 and R3 windows. Eagle1 would have been obscured from the N1285U pilot's view by the left wing.

At 1102:14.0, when the Eagle1 flight crew reported "...right downwind abeam. traffic to the left and right in sight," Eagle1 was at about 2,110 ft, 1.3 nm north and 0.4 nm west of the runway 26R threshold. N6ZP would have appeared in Eagle1's L1 window and was the only aircraft to Eagle1's left. N1285U would have appeared in Eagle1's R3 window. N1285U was descending through 1,650 ft, about 0.7 nm north and 0.5 nm west of the runway 26R threshold. Eagle1 would have remained obscured from the N1285U pilot's view by the left wing. Other airborne traffic to the right of Eagle1 at this time included a Piper airplane (N5442P), the helicopter (N8360R), and the Cessna 206 (N5058U).

At 1102:32.0, when the LC mistakenly instructed N6ZP to make a right 360° turn, intending the instruction for N1285U, Eagle1's CVR recorded the pilot ask "you still got the guy on the right side?"

N1285U was 0.8 nm away and would have appeared in Eagle1's R3 window (see figure 8a). Also to Eagle1's right were N8360R (on short final approach for runway 26L), N5442P (on a left base leg for runway 26L), and N5058U (which was climbing through 1,500 ft about 2.6 nm to the west of the runway 26R threshold). Eagle1 would have been obscured from the N1285U pilot's field of view by the left wing and strut (see figure 8b). Eagle1 started banking to the right, turning toward right base, shortly after this time.

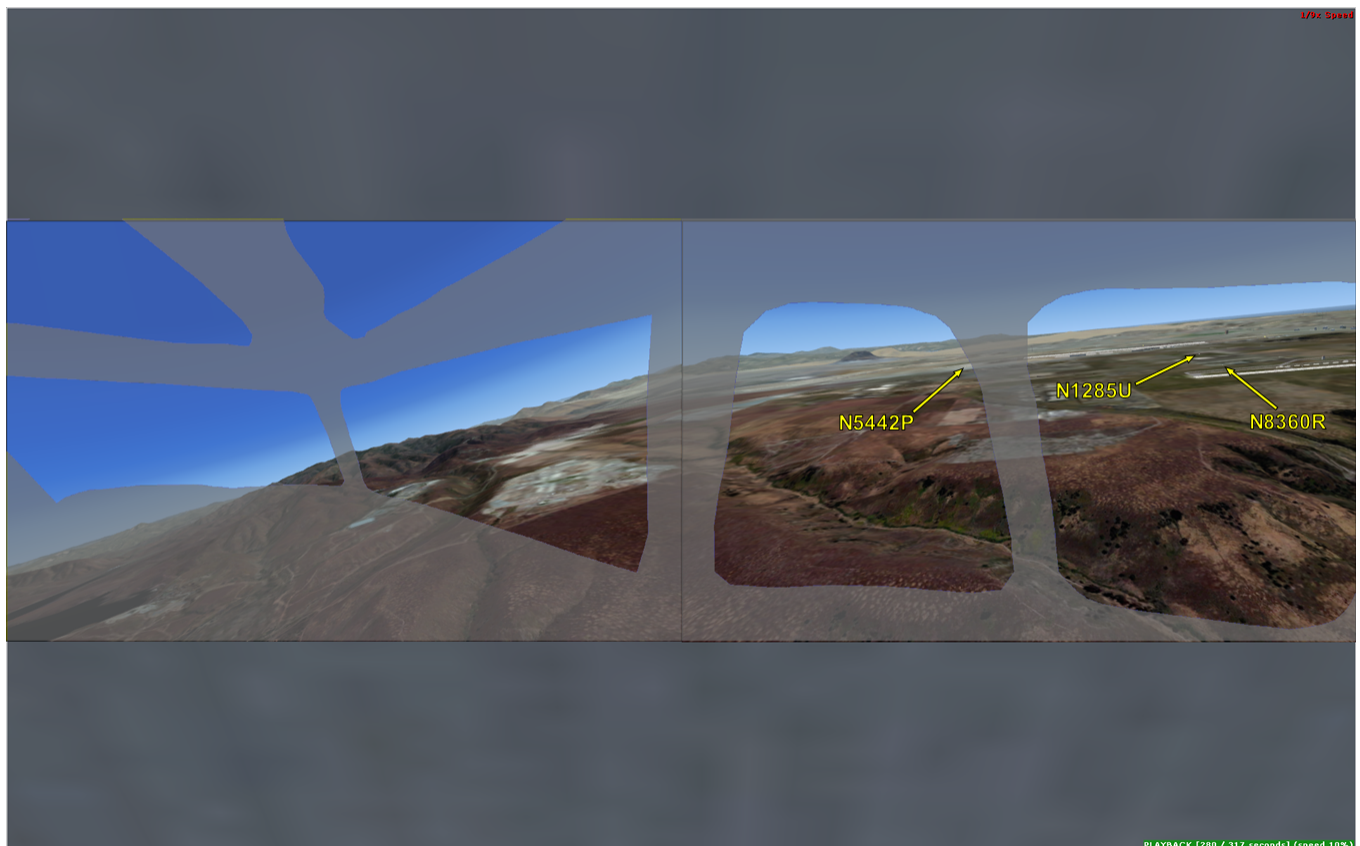


Figure 8a. View from the copilot seat of Eagle1 at 1102:32.4, when the airplanes were 0.8 nm apart.

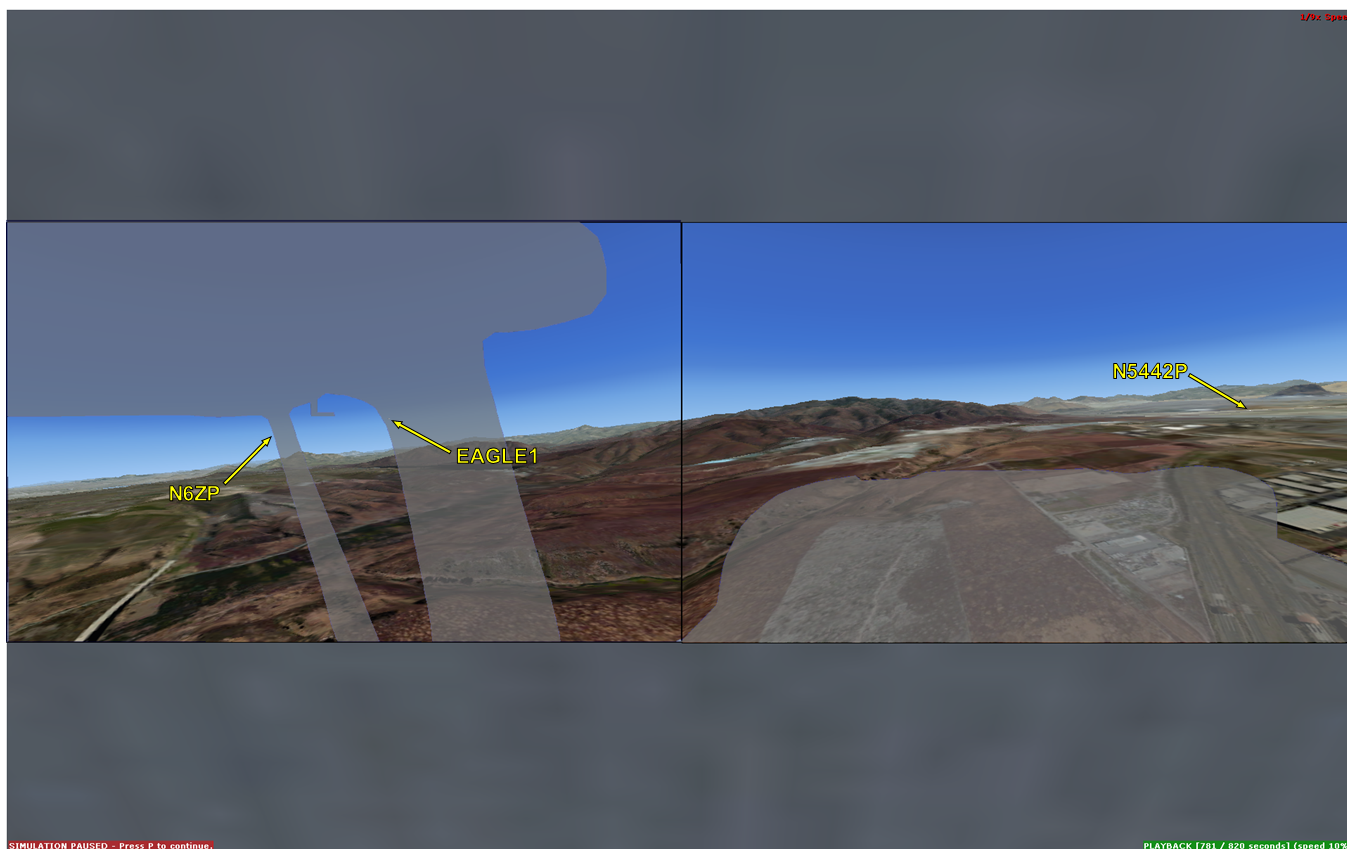


Figure 8b. View from the pilot seat of N1285U at 1102:32.4, when the airplanes were 0.8 nm apart.

At 1102:42.0, when the LC instructed the pilot of Eagle1 to "turn base two six right cleared to land," Eagle1 was descending through 1,960 ft in a right bank, about 1.3 nm north and 0.7 nm east of the runway 26R threshold. N1285U was descending through 1,460 ft, about 0.6 nm north and 0.3 nm east of the threshold, and would have appeared in Eagle1's R3 window (see figure 9a). Eagle1 would have appeared in the N1285U pilot's field of view near the edge or slightly behind the window post separating the left window from the windshield (see figure 9b). The airplanes were still about 0.8 nm away from each other.

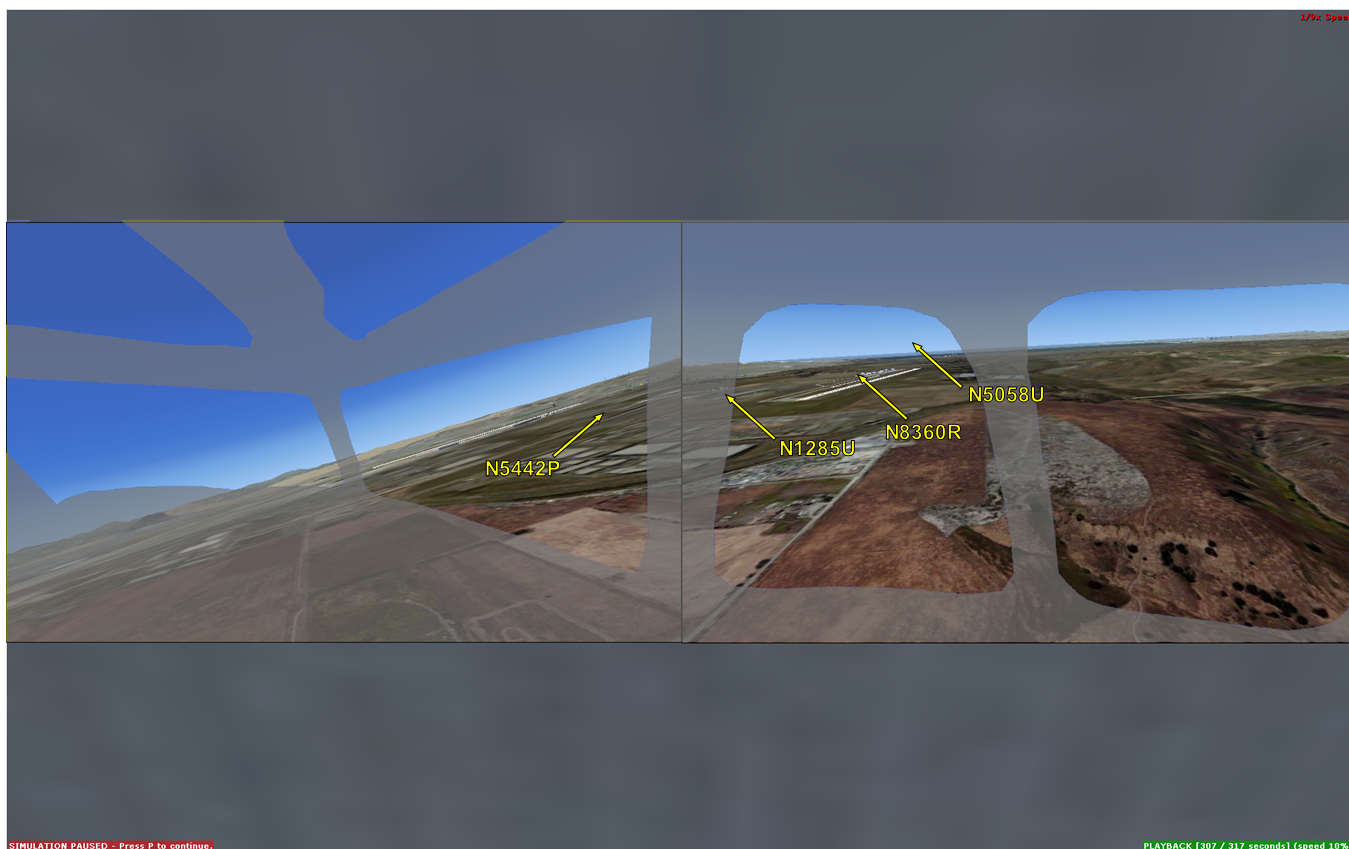


Figure 9a. View from the copilot seat of Eagle1 at 1102:42.0, when the airplanes were 0.8 nm apart.

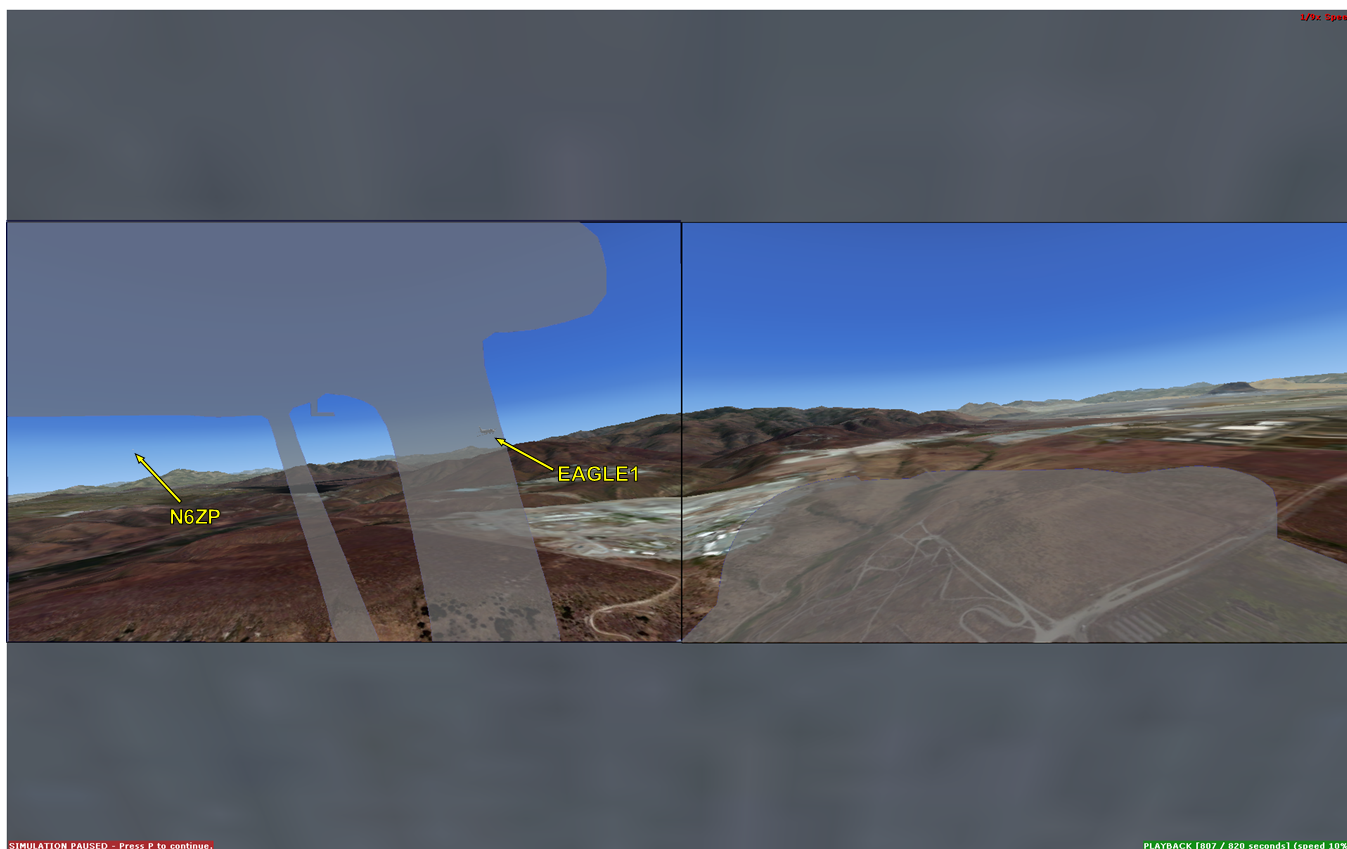


Figure 9b. View from the pilot seat of N1285U at 1102:42.0, when the airplanes were 0.8 nm apart.

At 1102:59.3, Eagle1's CVR recorded the pilot state "I see the shadow but I don't see him." The only aircraft close enough to Eagle1 to cast a shadow visible to Eagle1's pilot was N1285U, which was 0.5 nm away and would have appeared in the upper part of Eagle1's R2 window. At this time, Eagle1 may again have been obscured from the N1285U pilot's view by the post between the right window and the windshield.

At 1103:04.0, when the LC called N1285U, apparently realizing that he may have instructed the wrong airplane to make the right 360° turn, Eagle1 and N1285U were 0.3 nm apart, with Eagle1 descending through 1,490 ft and N1285U descending through 1,370 ft. N1285U would have appeared near the top left corner of Eagle1's R2 window, and Eagle1 may have remained obscured behind N1285U's left window post.

At 1103:08.0, when the controller asked the N1285U pilot if he was still on downwind, Eagle1 and N1285U were about 0.1 nm apart. N1285U may have been obscured by the post between Eagle1's R1 and R2 windows, and Eagle1 may have been obscured by N1285U's window post (see figures 10a and 10b).

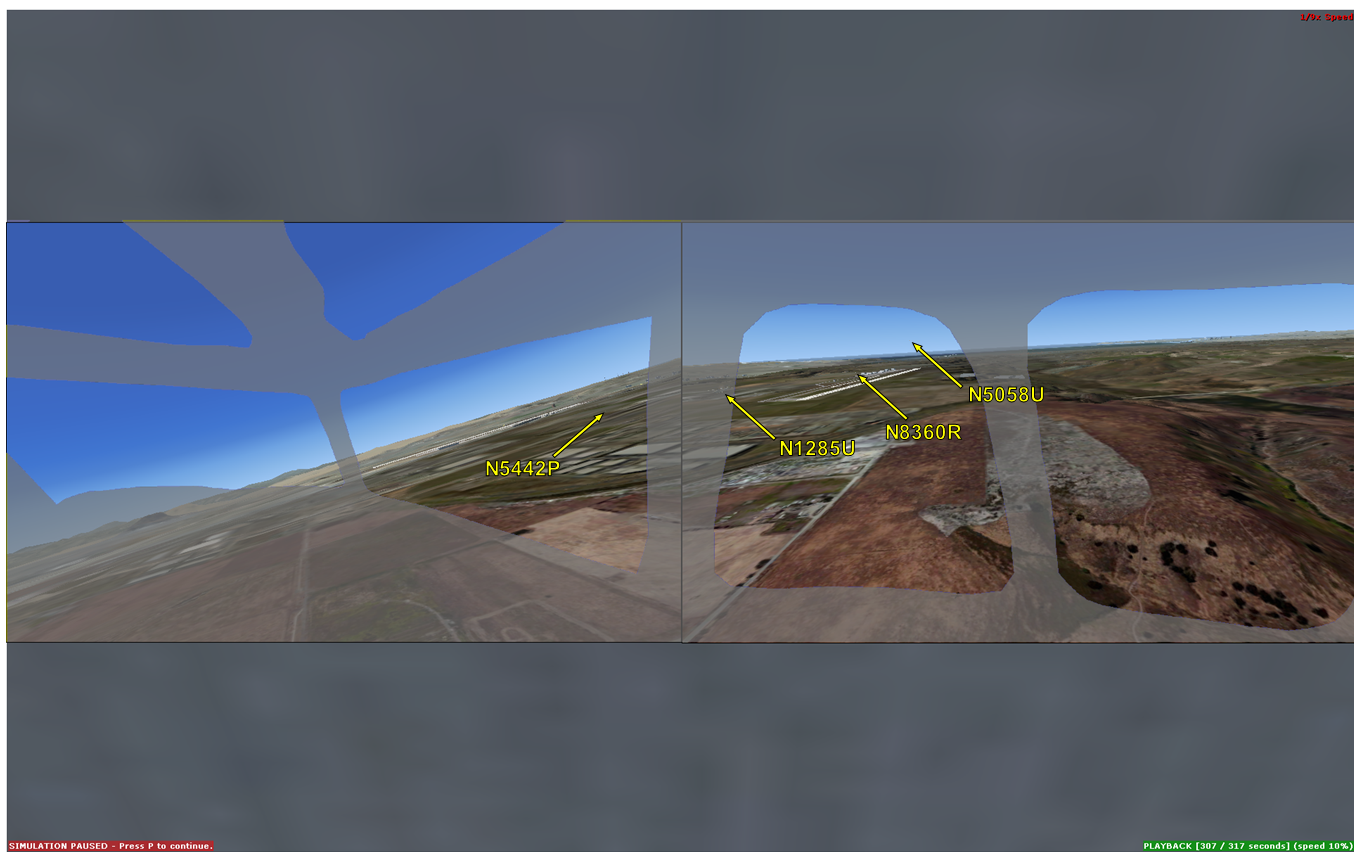


Figure 10a. View from the copilot seat of Eagle1 at 1103:08.0, when the airplanes were 0.1 nm apart.

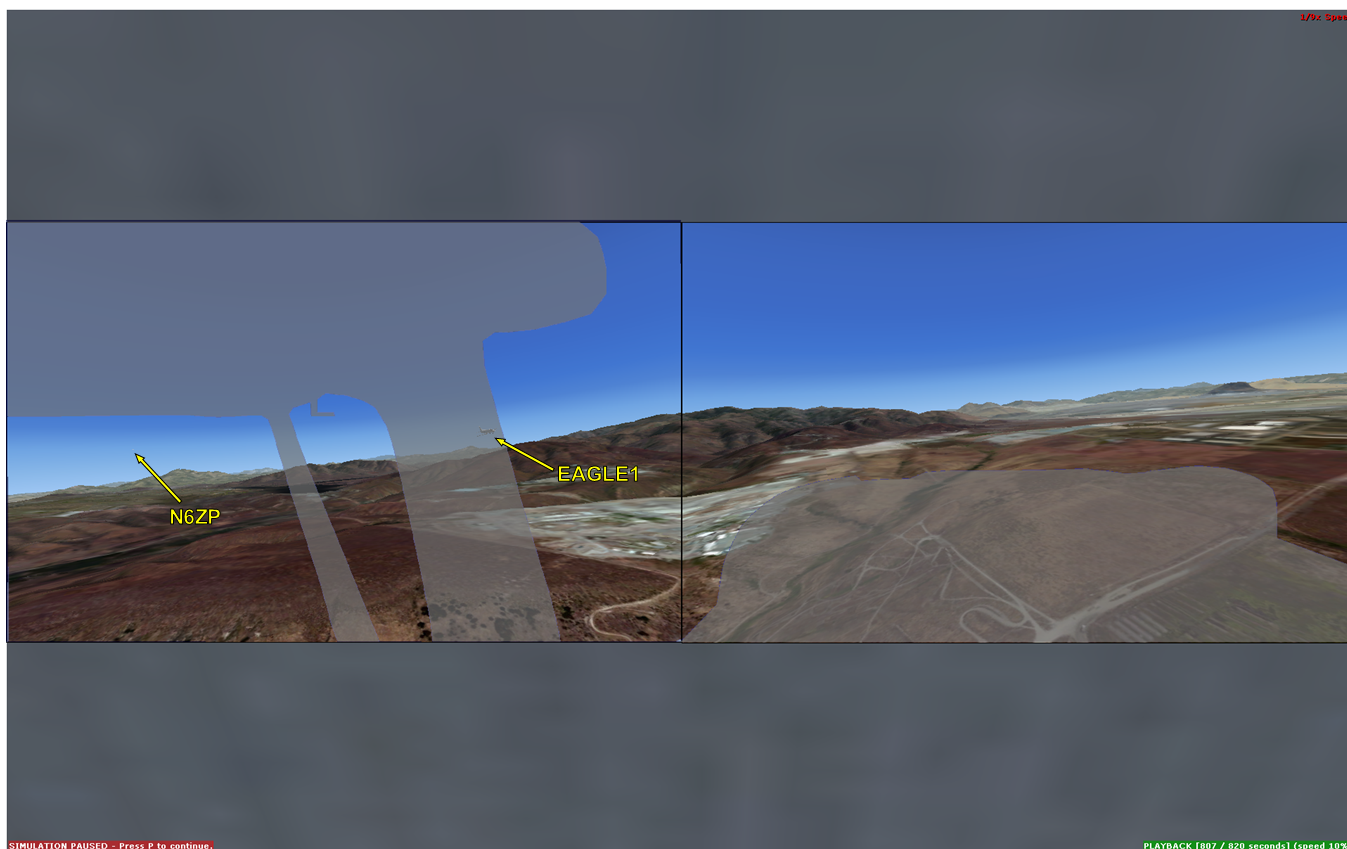


Figure 10b. View from the pilot seat of N1285U at 1103:08.0, when the airplanes were 0.1 nm apart.

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 transmit 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 pilots' 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.

For this accident, simulated in-cockpit displays of traffic information for both Eagle1 and N1285U were created based on the TIS-B information that would have been displayed to the pilots 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, 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 images from the NTSB's in-cockpit traffic display simulation presented in figures 11 through 13 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). In addition, the aircraft N numbers shown in figures 11 through 13 are included here for clarity but would not be presented in an actual display because none of the aircraft in the SDM pattern (except for N18WZ) were ADS-B Out equipped (an actual display could include the N number for N18WZ).

The NTSB's in-cockpit traffic display simulation for Eagle1 indicates that at 1059:04, open (outlined), cyan-colored, arrowhead-shaped targets representing the local traffic at SDM would have appeared at the 1 o'clock position, 8 nm from Eagle1, and traffic inbound for the San Diego area would have appeared at Eagle1's 9 to 11 o'clock position, 8 nm from Eagle1. N1285U would have been depicted 500 ft below Eagle1 east of the airport on a final approach leg. As Eagle1 continued its east-bound track toward SDM, N1285U would have disappeared from view (loss of radar contact). At 1059:48, as Eagle1 approached 6 nm from SDM, N6ZP would have appeared over SDM as an open arrowhead and turned right to remain in the traffic pattern for runway 26R. At 1100:16, N6ZP would have changed to a filled cyan-colored arrowhead before becoming established on the downwind leg at 1100:49. (N6ZP would eventually cross over the projected flightpath of Eagle1 at 1101:49, headed northeastbound.) At 1100:57, when Eagle1 was about 3.5 nm from the runway 26R threshold, N1285U would have reappeared on Eagle1's display as a filled, cyan-colored arrowhead at Eagle1's 1 o'clock position, about 2.5 nm from and 1,100 ft below Eagle1. At 1101:38, N1285U's symbol would have changed to alert status (a filled, yellow-colored arrowhead, enclosed by a yellow circle), and Eagle1 would have received an aural alert advising, "Traffic, 2 o'clock, low, less than 1 mile, climbing" (see figure 11).

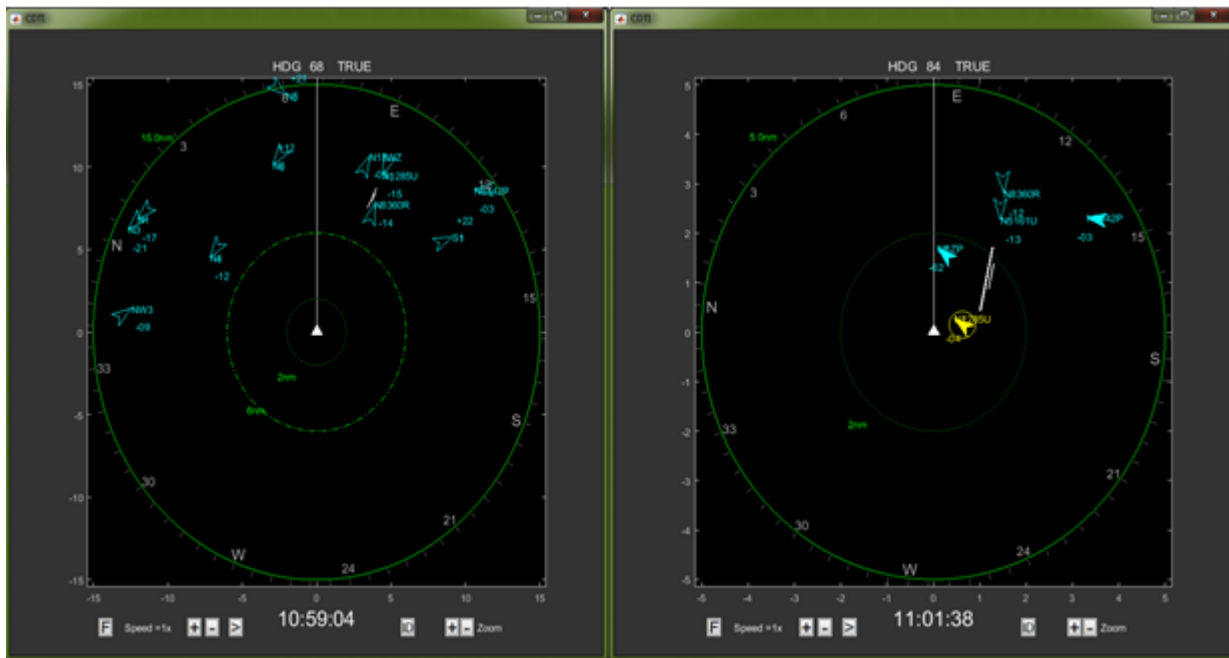


Figure 11. Simulated in-cockpit traffic display for Eagle1 at 1059:04 (left) and 1101:38 (right).

As shown in figure 12, at 1101:38, as N1285U turned onto the downwind leg and as Eagle1 was receiving its aural alert, N1285U's display would have depicted Eagle1 at N1285U's 8 o'clock position, 0.6 nm from and 400 ft above N1285U. At 1102:14, both Eagle1 and N1285U were positioned abeam the tower, and Eagle1 reported traffic to the left and right in sight. N6ZP would also have been shown on the displays departing the SDM area heading in a northeastern direction 400 ft above N1285U and at the same altitude as Eagle1.



Figure 12. Simulated in-cockpit traffic display for N1285U at 1101:38 (left) and 1102:14 (right).

At 1102:59.3, during Eagle1's base turn, the pilot stated, "I see the shadow but I don't see him." At this time, N1285U would have been depicted on Eagle1's display at Eagle1's 2 o'clock position, between Eagle1 and the runway 26R threshold, 1 nm from and 500 ft below Eagle1. At 1103:07, about 3 seconds before the collision, N1285U would have again changed to alert status (yellow, circled arrowhead), and Eagle1 would have received a second aural alert advising, "Traffic, 1 o'clock, same altitude, zero miles" (see figure 13). At the same time, Eagle1 would have changed to alert status on N1285U's display, and N1285U would have received an aural alert advising, "Traffic, 11 o'clock, same altitude, zero miles, descending." Additional details about the traffic information that could have been displayed during the accident scenario can be found in the Aircraft Performance and Cockpit Visibility Study.

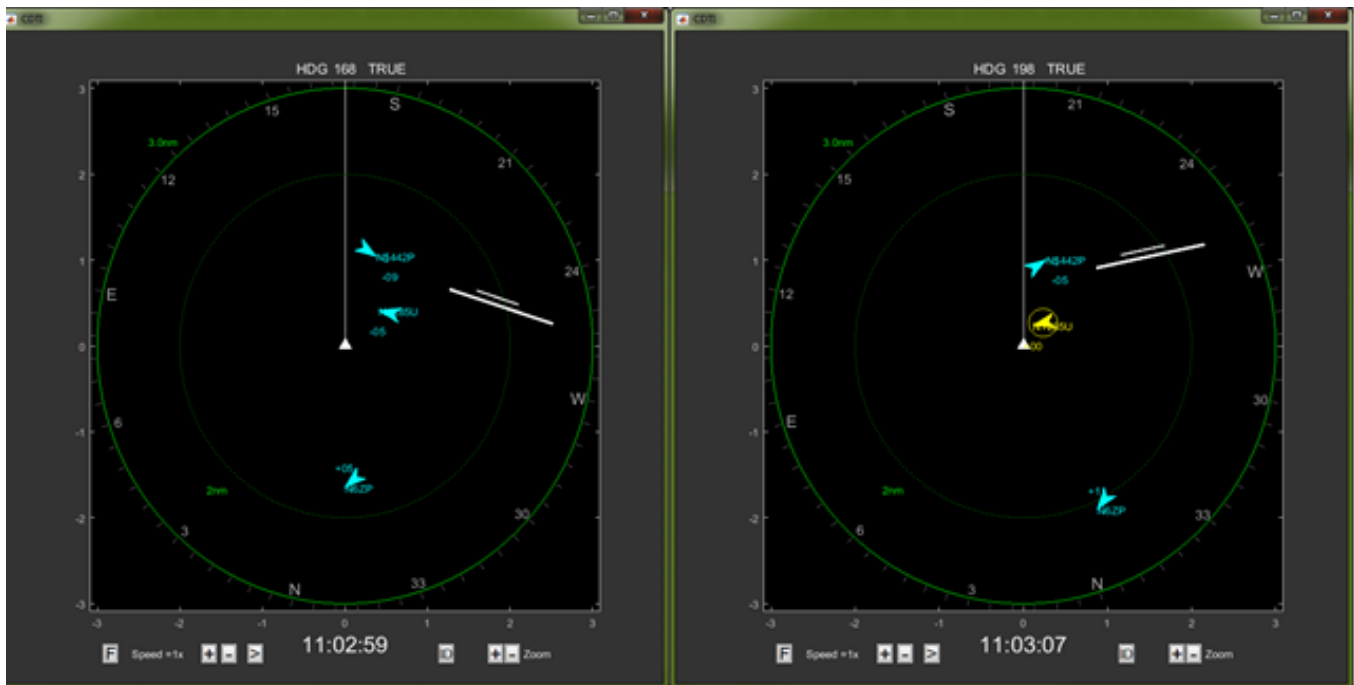


Figure 13. Simulated in-cockpit traffic display for Eagle1 at 1102:59 (left) and 1103:07 (right).

Additional Information

FAA 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 4-1-16, describes the manner in which pilots could expect to receive traffic safety alerts from ATC and states, in part, the following:

A safety alert will be issued to pilots of aircraft being controlled by ATC if the controller is aware the aircraft is at an altitude which, in the controller's judgment, places the aircraft in unsafe proximity to terrain, obstructions or other aircraft. The provision of this service is contingent upon the capability of the controller to have an awareness of a situation involving unsafe proximity to terrain, obstructions and uncontrolled aircraft. The issuance of a safety alert cannot be mandated, but it can be expected on a reasonable, though intermittent basis. Once the alert is issued, it is solely the pilot's prerogative to determine what course of action, if any, to take. This procedure is intended for use in time critical situations where aircraft safety is in question. Noncritical situations should be handled via the normal traffic alert procedures....

Controllers will immediately issue an alert to the pilot of an aircraft under their control if they are aware of another aircraft which is not under their control, at an altitude which, in the controller's judgment, places both aircraft in unsafe proximity to each other. With the alert, when feasible, the controller will offer the pilot the position of the traffic if time permits and an alternate course(s) of action.

Title 14 *CFR* 91.123, "Compliance with ATC Clearances and Instructions," states the following:

(a) When an ATC clearance has been obtained, no pilot in command may deviate from that clearance unless an amended clearance is obtained, an emergency exists, or the deviation is in response to a traffic alert and collision avoidance system resolution advisory. However, except in Class A airspace, a pilot may cancel an IFR flight plan if the operation is being conducted in VFR weather conditions. When a pilot is uncertain of an ATC clearance, that pilot shall immediately request clarification from ATC.

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, 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 instrument flight rules 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.

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 [Intermittent Positive Control] IPC/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.

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 2-1-6, "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.

Research on Workload

According to Mica R. Endsley and Mark D. Rodgers in a 1997 report titled *Distribution of Attention, Situation Awareness, and Workload in a Passive Air Traffic Control Task: Implications for Operational Errors and Automation* (FAA Report No. DOT/FAA/AM-97/13), the cognitive effects of increasing workload may include memory deficits, distraction, narrowing of attention, decreased situational awareness, and increased errors (such as readback errors or giving instruction to the wrong aircraft). Specifically, Endsley and Rodgers write the following:

This study reveals many interesting findings on the role of situation awareness and workload in operational errors. Significant deficiencies in the ongoing situation awareness of the subjects were present in this study. They had a fairly low ability to report on the existence of many aircraft, or accurately recall their location or many of their parameters. Their accuracy was significantly impacted by the number of aircraft present in the scenario and, to a lesser degree, by perceived workload.

Administrative Information

Investigator In Charge (IIC):	Swick, Andrew
Additional Participating Persons:	Bob Hendrickson; FAA; Washington, DC John J Mecalo; Sabreliner; Perryville, MO Brian Weber; Textron Aviation; Wichita, KS Mark Morter; BAE Systems; Mojave, CA Shane Terpstra; Plus One Flyers, Inc; La Jolla, CA Grant Kowalchick; Navy-NAWCWD; NAS-Point Mugu, CA
Original Publish Date:	November 15, 2016
Last Revision Date:	
Investigation Class:	Class
Note:	The NTSB traveled to the scene of this accident.
Investigation Docket:	https://data.nts.gov/Docket?ProjectID=91793

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