

# National Transportation Safety Board

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## **ADS-B AND VISIBILITY STUDY**

Aircraft Performance Study

By

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## **A. ACCIDENT**

Location: Dallas, Texas  
Date: 12 November 2022  
Time: 1322 central standard time (CST)  
1922 UTC  
Airplane 1: Boeing B-17G, N7227C  
Airplane 2: Bell P-63F, N6763

## **B. SUMMARY**

On November 12, 2022, about 1322 central standard time, a Boeing B-17G airplane, N7227C and a Bell P-63F airplane, N6763, collided in midair at the Dallas Executive Airport (RBD), Dallas, Texas. A post impact fire ensued. The pilot, co-pilot, and three crewmembers onboard the B-17G and the pilot of the P-63F were all fatally injured. There were no ground injuries reported. Both airplanes were operated under the provisions of Title 14 *Code of Federal Regulations* Part 91 in the Wings Over Dallas Airshow, which was conducted by the Commemorative Air Force.

## **C. PERFORMANCE STUDY**

### **1.0 Aircraft**

#### **1.1 Boeing B-17G, N7227C**

The Boeing B-17G, a variant of the B-17 Flying Fortress, is a four-engine heavy bomber developed for the United States Army Air Corps in the 1930s. The G variant was the most common with 8,680 built between 1943 and 1945. The airplane has a wingspan of 103 ft 9 in, a gross weight of 54,000 lbs, and a cruise speed of 158 kts. N7227C went by the callsign "Raiders" and was the lead airplane in the five-airplane bomber flight.



Photo Copyright © Hector Antonio -HR Planespotter  
**Figure 1.** Boeing B-17, N7227C.

## **1.2 Bell P-63F, N6763**

The Bell P-63 Kingcobra is an American fighter developed during WWII for the United States Army Air Corps. The single-engine airplane has a wingspan of 38 ft 4 in, a gross weight of 8,800 lbs, and a maximum speed of 360 kts. N6763 was the third of three airplanes in the fighter flight.



**Figure 2.** Bell P-63, N6763.

## 2.0 Available Data

This performance study is based on Automatic Dependent Surveillance-Broadcast (ADS-B) data provided by the Federal Aviation Administration (FAA). ADS-B broadcasts an airplane's Global Positioning System (GPS) position and other data to the ground where it is recorded. The GPS position has an accuracy of approximately 20 meters (65 ft) in both the horizontal and vertical dimensions. ADS-B latitude and longitude data (but no altitude) were available for the B-17 and latitude, longitude, and altitude data were available for the P-63. Additionally, latitude, longitude, and geometric altitude data were available for five of the six other airplanes participating in the military airplane fly-by at the time of the accident and for an additional airplane providing a paying passenger demonstration flight that was landing at the time of the accident.

Additionally, the B-17 was equipped with an Avidyne unit which recorded latitude, longitude, and altitude. The last Avidyne position record was at 13:21:52.5. The ADS-B data recorded one additional latitude and longitude position at 13:21:53.4.

A Video Study [1] was conducted using videos of the collision. The Video Study produced position (latitude, longitude, and altitude above ground) and attitude (roll, pitch, and yaw) information for the final three seconds of flight for the P-63 and B-17.

Recorded altitude data for all airplanes were adjusted such that each airplane's altitude was consistent with elevation during their take-off rolls and height above the geoid. Altitude and position data for the B-17 and P-63 were adjusted such that the ADS-B and Avidyne flight paths smoothly transitioned to the flight paths determined from the Video Study.

A recording of the air boss frequency of the airshow was provided by the FAA and a transcription was created [2]. This recorded the communications between the air boss, the airplanes performing in the show, other airplanes taking off and landing at the airport, the person narrating to the crowd, and the crew doing pyrotechnics.

### **3.0 Weather**

Weather was recorded for 12:53 at Dallas Executive Airport. The temperature was reported as 48°F (9°C), the dew point was 25°F (-4°C), and the barometric setting was 30.3 inHg. Winds were 14 kts, gusting to 18 from 350°. Skies were clear and visibility was ten statute miles.

### **4.0 Air Boss**

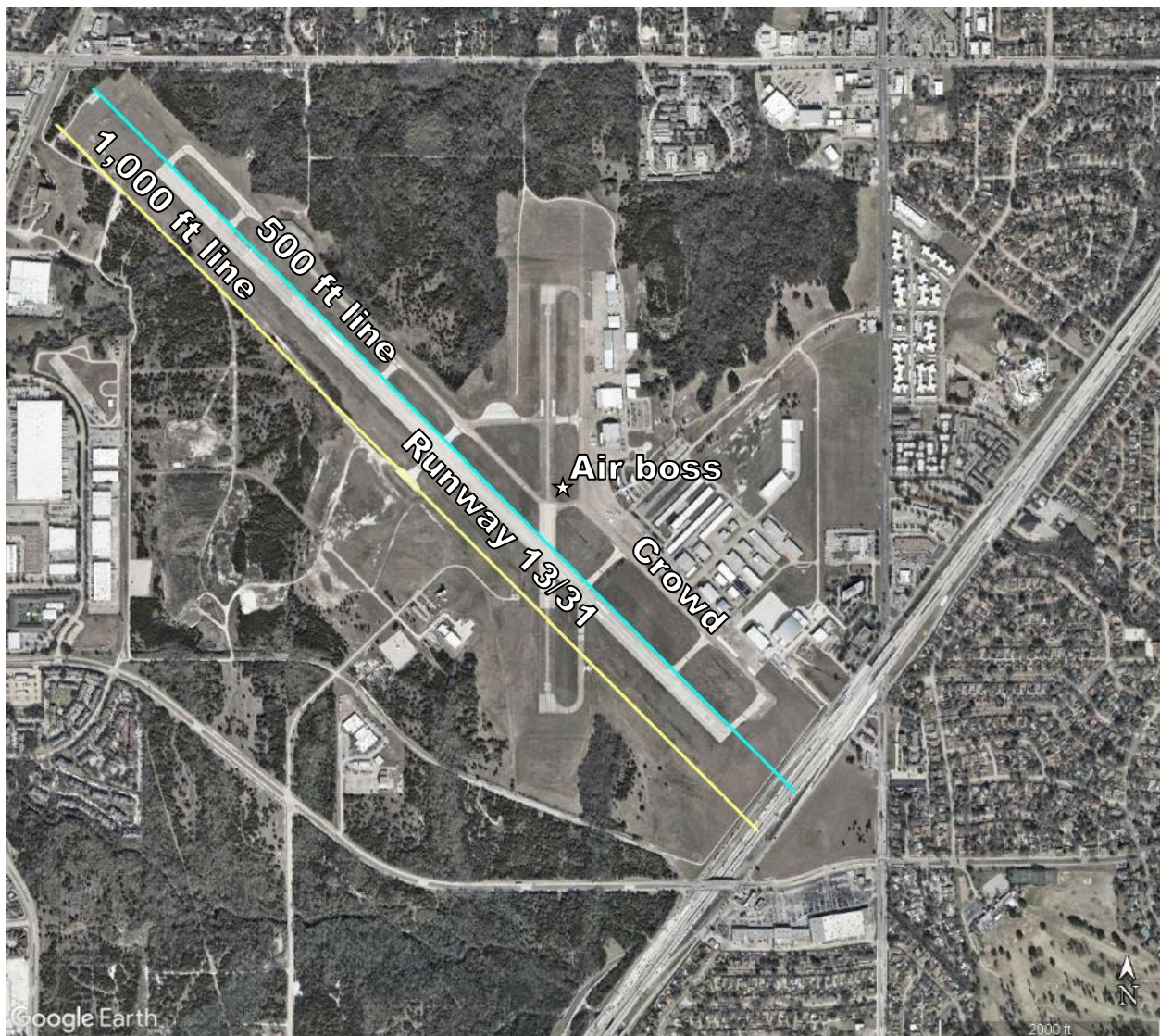
The airshow was controlled by an air boss who was responsible for air show operations on the taxiways, runways, and the surrounding air show demonstration areas. In addition, the air boss controlled demonstration flights for paying passengers that were separate from the flying displays of military aircraft. The air boss also communicated with the narrator of the air show and the pyrotechnics crew. The air boss told the participating air show airplanes when and where to taxi, when to take-off, and dictated the flight paths of the airplanes while flying in the show.

### **5.0 Flight Path**

The ADS-B position data were used to determine groundspeeds for all airplanes and then, using winds and meteorological conditions, calibrated airspeeds were calculated. A simplified aerodynamic model was created for each type of airplane to estimate body attitudes throughout the flight path. Additionally, the pressure altitudes recorded by ADS-B were corrected and are shown as height above ground (agl) throughout this report. As discussed in Available Data, the accuracy of GPS is approximately 20 meters (65 ft) in both the horizontal and vertical dimensions, so

positions and altitudes may not be precisely reflective of the airplane's location at a specific time.

The Wings over Dallas Airshow was held at the Dallas Executive Airport, six miles southwest of Dallas, Texas (Figure 3). The airport has two runways: runway 13/31 which is 7,136 ft long and 100 ft wide and runway 17/35 which is 3,800 ft long and 150 ft wide. The airshow was using runway 13/31 for takeoffs and landings. The airshow had two designated show lines. The 500 ft show line, shown in Figure 3 in blue, was 500 ft from the crowd and along the right edge of runway 31. The 1,000 ft show line, shown in yellow, was 1,000 ft from the crowd to the left of runway 13. The air boss was standing on airstairs at the intersection of taxiway A4 and runway 17/35.



**Figure 3.** Dallas Executive Airport with primary runway, show lines, crowd, and Air boss locations noted.

The airshow at the time of the accident consisted of eight airplanes flying in two formations. Figure 4 shows a picture of each airplane. Table 1 lists their type, N number, and call sign. ADS-B data was available for all airplanes except N25YR, the B-25 that was the last airplane in the bomber formation. Additionally, a PT-17 Stearman, N7058Q was landing on runway 31, under the control of the air boss, just prior to the accident and will be discussed further in the Communications section of this report.

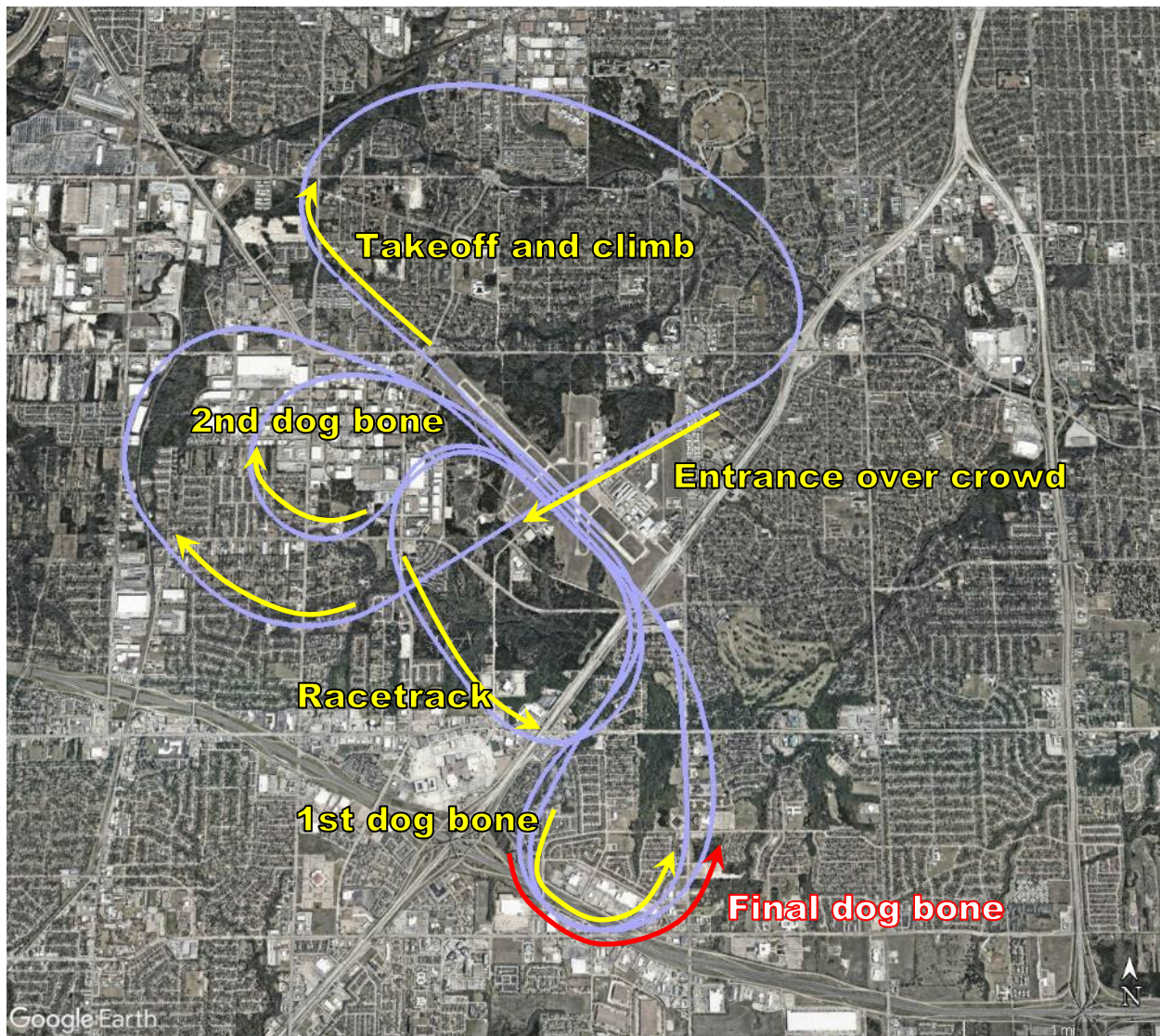


**Figure 4.** Other airplanes in formation, from top left: B-24, N24927; SB2C, N92879; B-25, N9643C; B-25, N25YR; P-51, N5428V; and P-51, N61429.

**Table 1.** Airplanes participating in airshow at the time of the collision. Accident airplanes bolded.

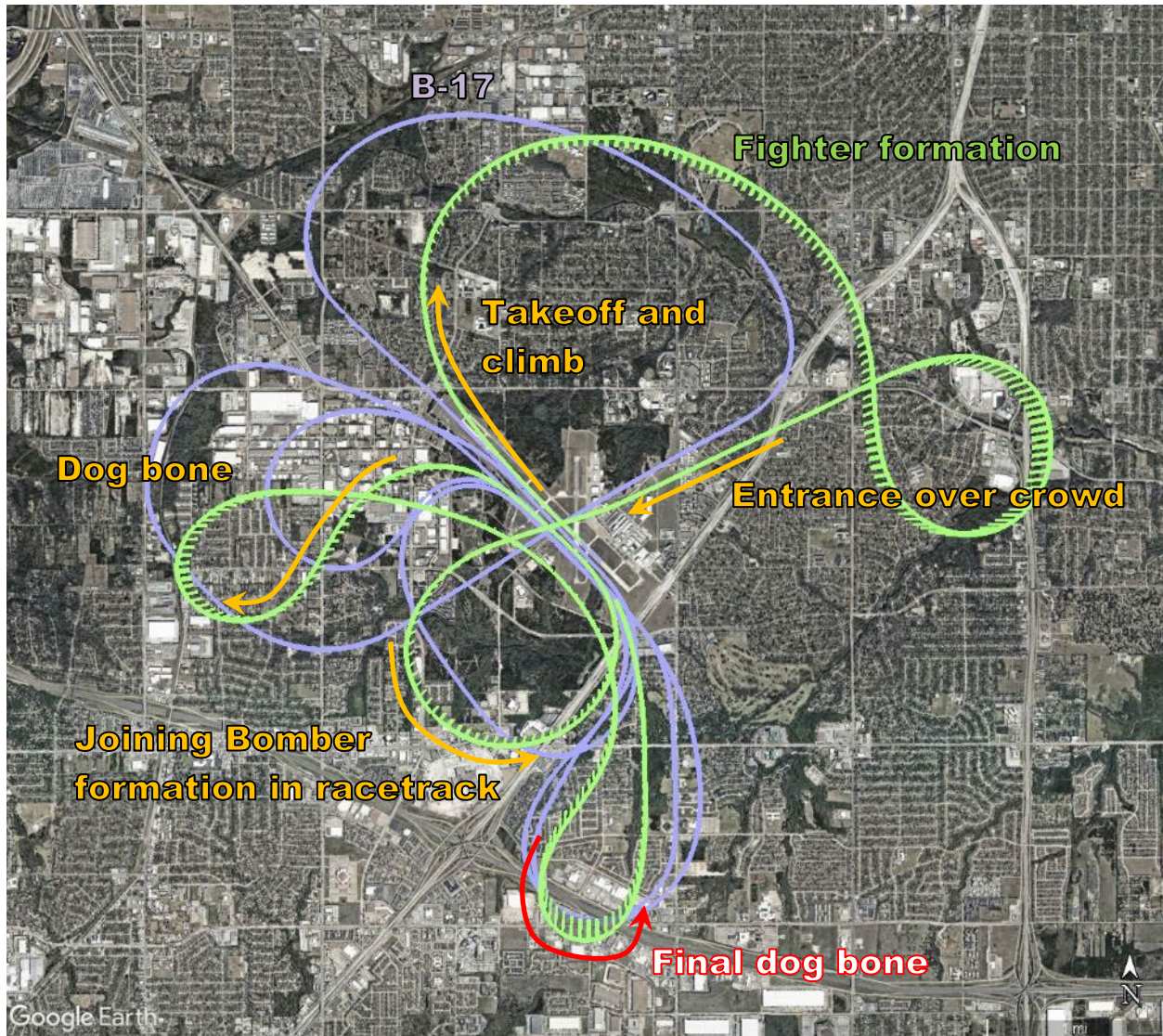
|                   |             |               |                      |                   |
|-------------------|-------------|---------------|----------------------|-------------------|
| Bomber formation  |             |               |                      |                   |
| <b>Lead</b>       | <b>B-17</b> | <b>N7227C</b> | <b>Texas Raiders</b> |                   |
| 2                 | B-24        | N24927        | Diamond Lil          |                   |
| 3                 | SB-2C       | N92879        | Helldiver            |                   |
| 4                 | B-25        | N9643C        | Devil Dog            |                   |
| 5                 | B-25        | N25YR         | Yellow Rose          | No ADS-B recorded |
| Fighter formation |             |               |                      |                   |
| Lead              | P-51        | N5428V        | Gunfighter           |                   |
| 2                 | P-51        | N61429        | Redtail              |                   |
| <b>3</b>          | <b>P-63</b> | <b>N6763</b>  | <b>Cobra</b>         |                   |

The B-17 took off from runway 31 at 13:10:30 and was followed by the B-24 at 13:11:00 and the SB-2C at 13:11:30. The three airplanes climbed and made a wide 270° right turn such that they flew into the show at about 1,000 ft agl from behind the crowd (labeled "Entrance over crowd" on Figure 5) and were joined by the already flying B-25s at about 13:13:30. The now five-plane Bomber group turned 270° to the right and flew along the 1,000 ft line in the direction of runway 13. The group then executed a right 90°, left 270° "dog bone" maneuver to fly back up the 1,000 ft line in the direction of runway 31 (labeled "1<sup>st</sup> dog bone"). They then made a left racetrack turn away from the crowd (labeled "Racetrack") to be joined by the Fighter group.



**Figure 5.** B-17 flight path during show. Maneuvers highlighted in yellow and final turn highlighted in red.

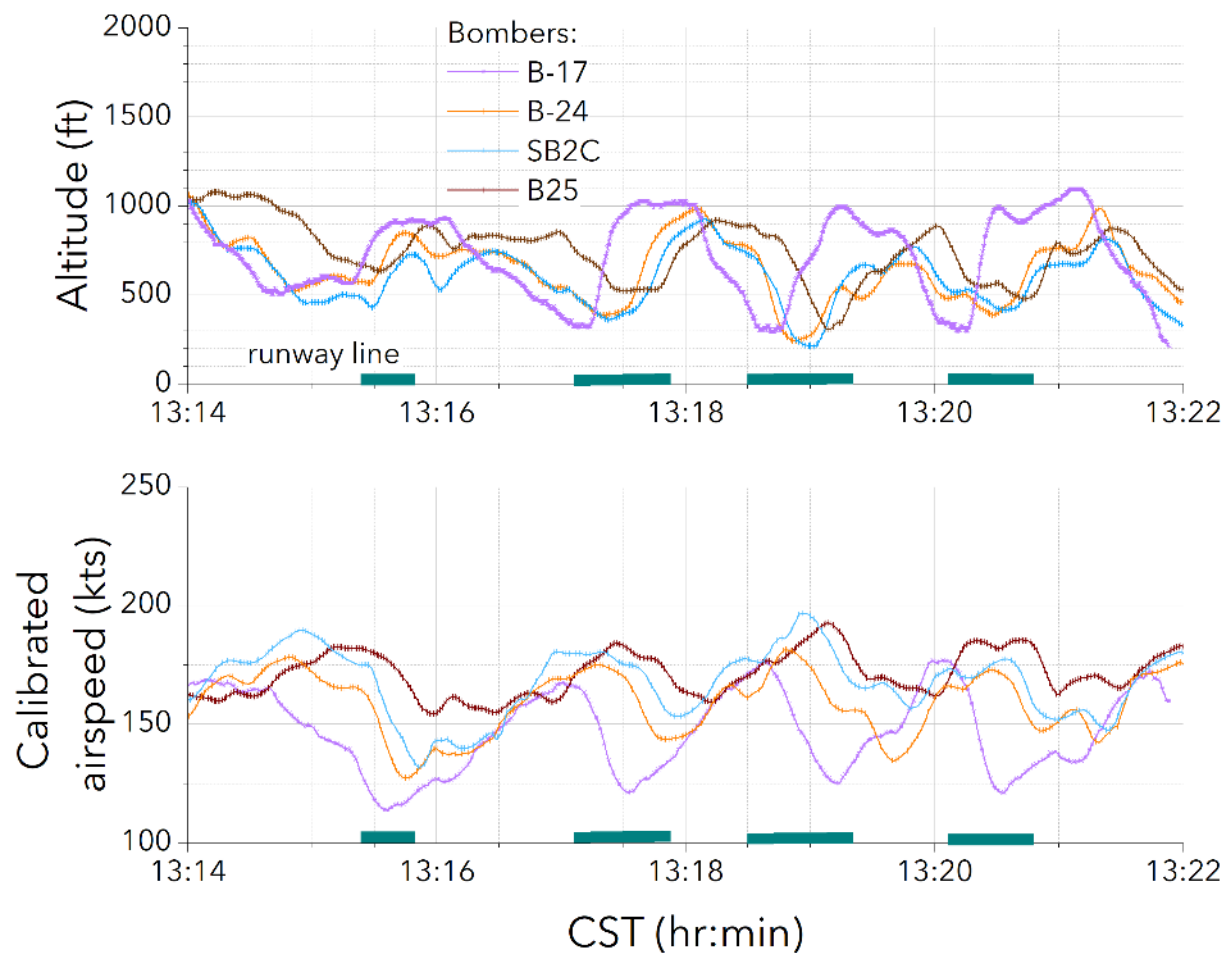
The P-51 Gunfighter took off from runway 31 at 13:14:30, followed by the P-51 Redtail at 13:14:45, and the P-63 at 13:15:00. The Fighters climbed and began a wide right 180° turn, circled once behind the crowd, and entered in over the crowd and the runway (Figure 6). The airplanes' altitudes were staggered with the lead P-51 at 1,100 ft agl, the second P-51 at 1,000 ft agl, and the P-63 at 900 ft agl. This 100 ft altitude separation remained mostly consistent throughout the show. The Fighters joined the Bombers in the left turn and flew up runway 31 along the 1,000 ft line at about 13:18:50.



**Figure 6.** B-17 flight path (lavender) and Fighter formation flight path (green) during show. Maneuvers highlighted in orange and final turn highlighted in red.

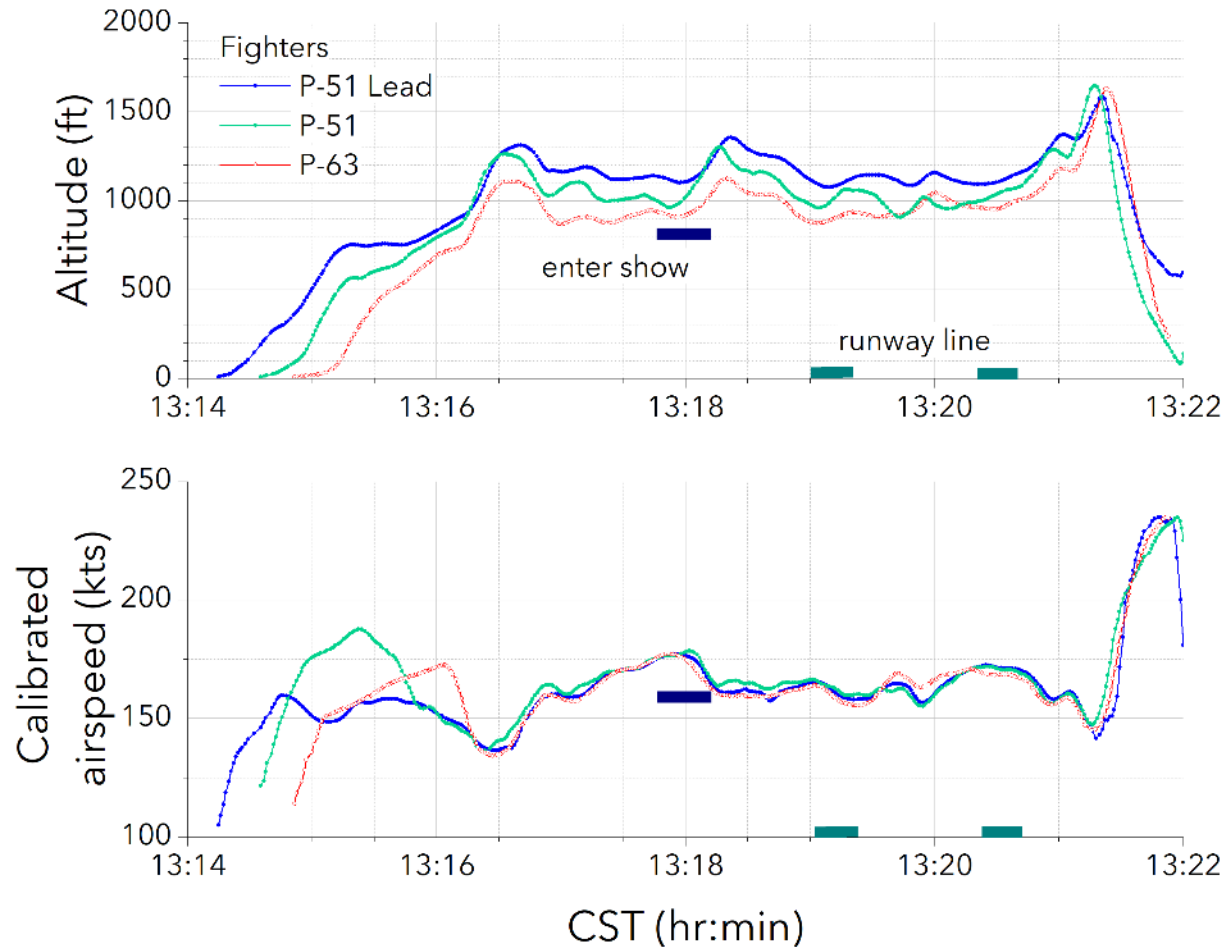
The airplanes then made a left 90°, right 270° dog bone maneuver with the Bombers flying back down the 1000 ft line in the runway 13 direction and the Fighters another 700 ft away from crowd. The three Fighters were behind the lead B-17, but alongside the B-24 and SB2C. The Fighters were about 1,000 ft agl and the B-24 and SB2C at 500 ft.

During each runway pass, the Bombers descended to between 200 ft agl and 500 ft agl and then climbed for the turning maneuvers (Figure 7). The B-17 was the slowest of the Bomber formation, with speeds varying between 110 and 170 kts of airspeed. The other Bombers speeds varied between 130 and 190 kts. The formation order was maintained by the B-17 making smaller, tighter dog bone turns as the other airplanes made wider turns.



**Figure 7.** Bomber formation altitude above ground and calibrated airspeed. Runway passes are underlined in dark green.

The Fighters' speeds were evenly matched allowing them to fly in close formation with about a 100 ft altitude separation (Figure 8). While in formation with the Bombers, their airspeeds varied between 150 and 170 kts until the final dog bone maneuver.



**Figure 8.** Fighter formation altitude above ground and calibrated airspeed. The time they entered the show is underlined in navy. Runway passes are underlined in dark green.

The Fighters were instructed to follow the Bombers through a 90° right turn, but during the 270° left turn portion of the dog bone maneuver were to get in front of the Bombers. The B-17 entered the right 90° portion of the dog bone maneuver at 13:20:25 and was between 800 and 1,000 ft above ground level (agl) and below 130 kts calibrated airspeed for much of the first right and then left turns.

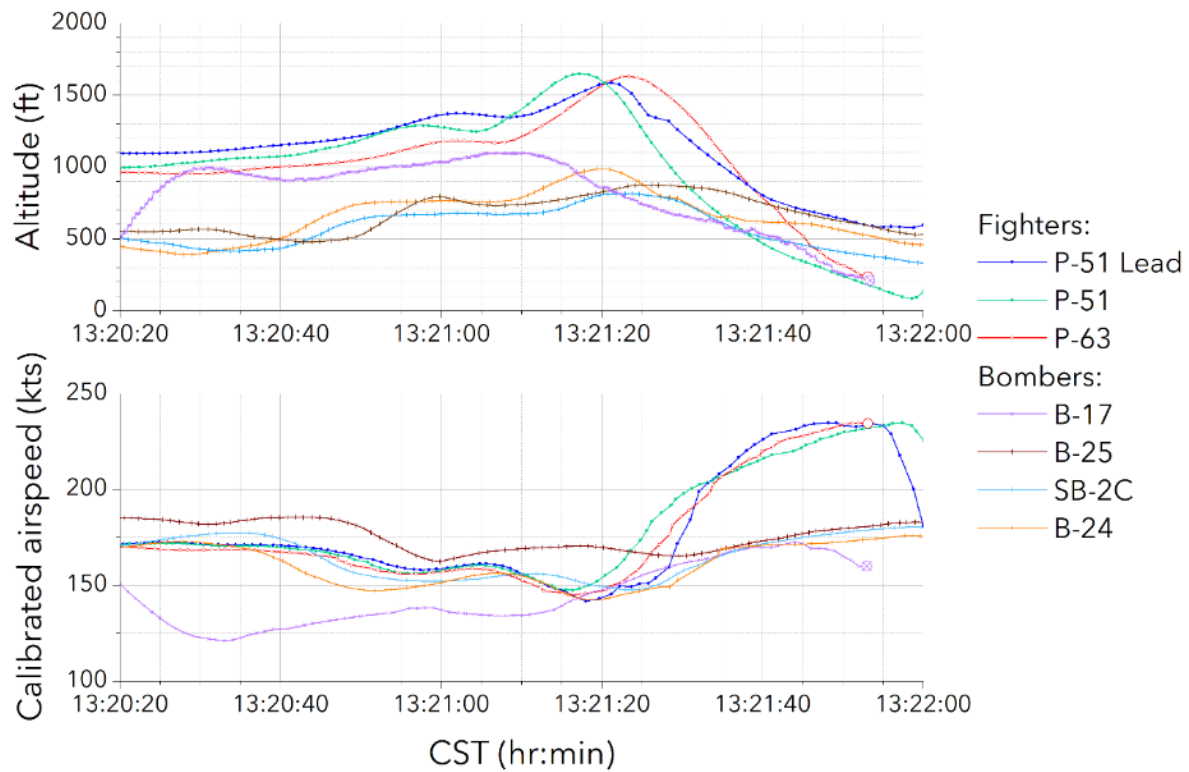
The B-24 and SB2C entered the right 90 at 13:20:45 at an average altitude of 600 ft agl and climbing at a speed of about 160 kts.

The Fighter group entered the right 90 at 13:20:50 at altitudes between 1,000 and 1,200 ft agl and climbing. The Fighters' speeds were 160 kts and slowing as they climbed.

The first B-25 (N9643C) entered the right 90 at 13:21 at an altitude of 800 ft agl and a speed of 160 kts.



**Figure 9.** Final turn with final ADS-B point at 13:21:53 for all airplanes. Looking southwest.



**Figure 10.** Altitude and calibrated airspeed for all airplanes in final turn. Last data points for B-17 and P-63 enlarged to highlight.

The Fighters climbed to an altitude above 1,600 ft agl while making a tighter 270° left turn than the Bombers who stayed under 1,000 ft agl. At about 13:21:20, the Fighters reached the apex of their climb and turn. They descended in echelon (N5428V, N61429, and N7227C) and increased speed from 150 kts to 230 kts.

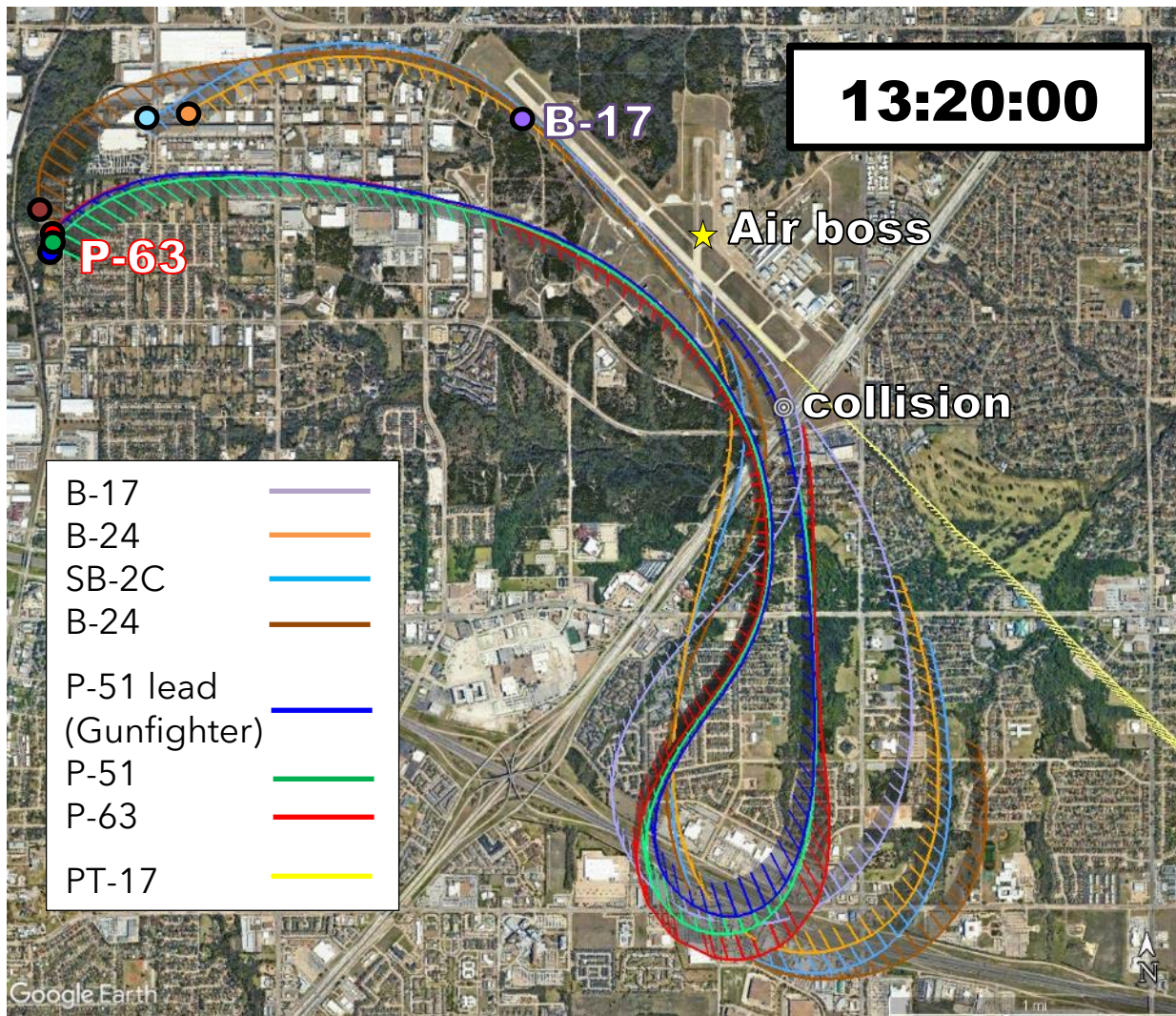
The lead P-51 began to pull ahead of the B-17 at 13:21:38. The P-51 was at 880 ft agl and 200 kts. It was 1,600 ft to the left of the B-17, which was at 550 ft agl and 170 kts. The second P-51 pulled ahead of the B-17 at 13:21:45. The second P-51 was at 320 ft agl and 220 kts. It was 1,000 ft to the left of the B-17, which was at 425 ft agl and 170 kts. Both P-51's were in a left bank, bellies towards the Bomber line, and coming onto the 1,000 ft show line.

The P-63 was about three seconds behind the second P-51 and closely followed its flight path until about 13:21:47. At this point the P-63's flight path no longer curved towards the 1,000 ft line like the P-51s, but was somewhat straighter, possibly towards the 500 ft show line. The P-63 was descending at a rate of 1,500 fpm and its airspeed was just above 230 kts.

The B-17 was also descending, but at a slower rate. The B-17's flight path was curving left towards the 1,000 ft line. The final ADS-B data points for both airplanes were at 13:21:53.4. The final ADS-B points were 150 ft apart horizontally and at nearly the same altitude. The airplanes collided shortly after.

## **6.0 Communications**

The air boss frequency was recorded for the Dallas airshow and a transcript was created [2]. Figure 11 shows the location of the four bombers and three fighters at 13:20:00. Additionally, the location of the midair collision is marked with a circle and the air boss' location is marked with a yellow star. The yellow flight path is that of a Stearman PT-17 (N7058Q). The PT-17 was providing a paying passenger demonstration flight, and the air boss controlled all take-offs and landings from the airport during the airshow. Its location at 13:20:00 was outside of the figure. Figure 11 shows the satellite imagery from Google Earth in color, but subsequent figures will be in grayscale to better display the colored flight tracks. Communication times are rounded to the nearest second.

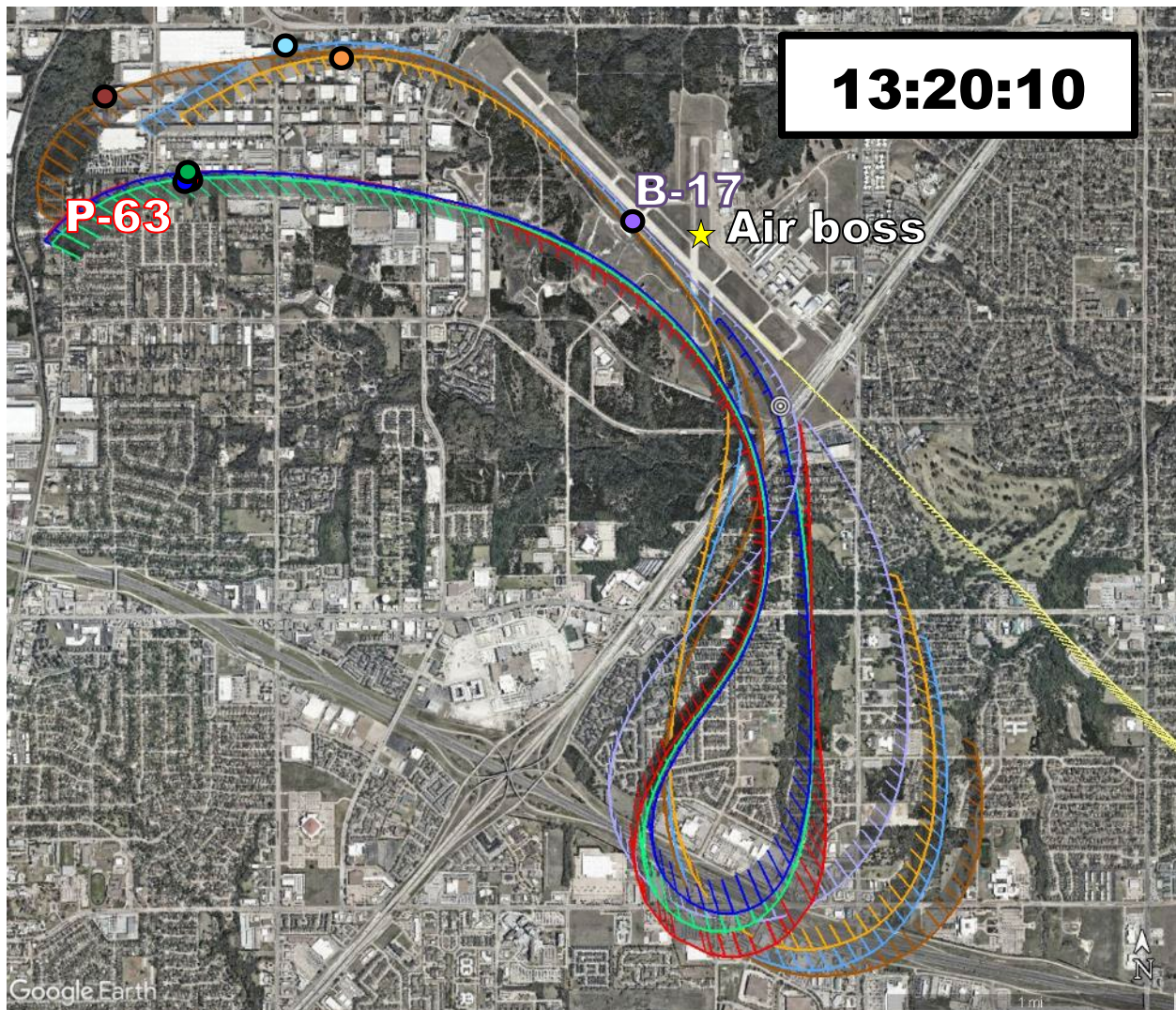


**Figure 11.** Flight for the final two minutes before collision. Positions of airplanes at 13:20:00 are highlighted with circles. The B-17 and P-63 are further labeled. The approximate collision location is shown by a double circle.

At a time between 13:19:34 and 13:20:10<sup>1</sup>, the air boss instructed “Fighters, can you walk your way up to the B-17? I’m going to break y’all out after this um-” and then continued “you’re going to end up breaking left” and finished “so you’re going to follow the bombers to the right ninety out and then you’re going to roll back in left and be on the five hundred foot line if y’all want to set up an echelon for a break so y’all can get in trail.”

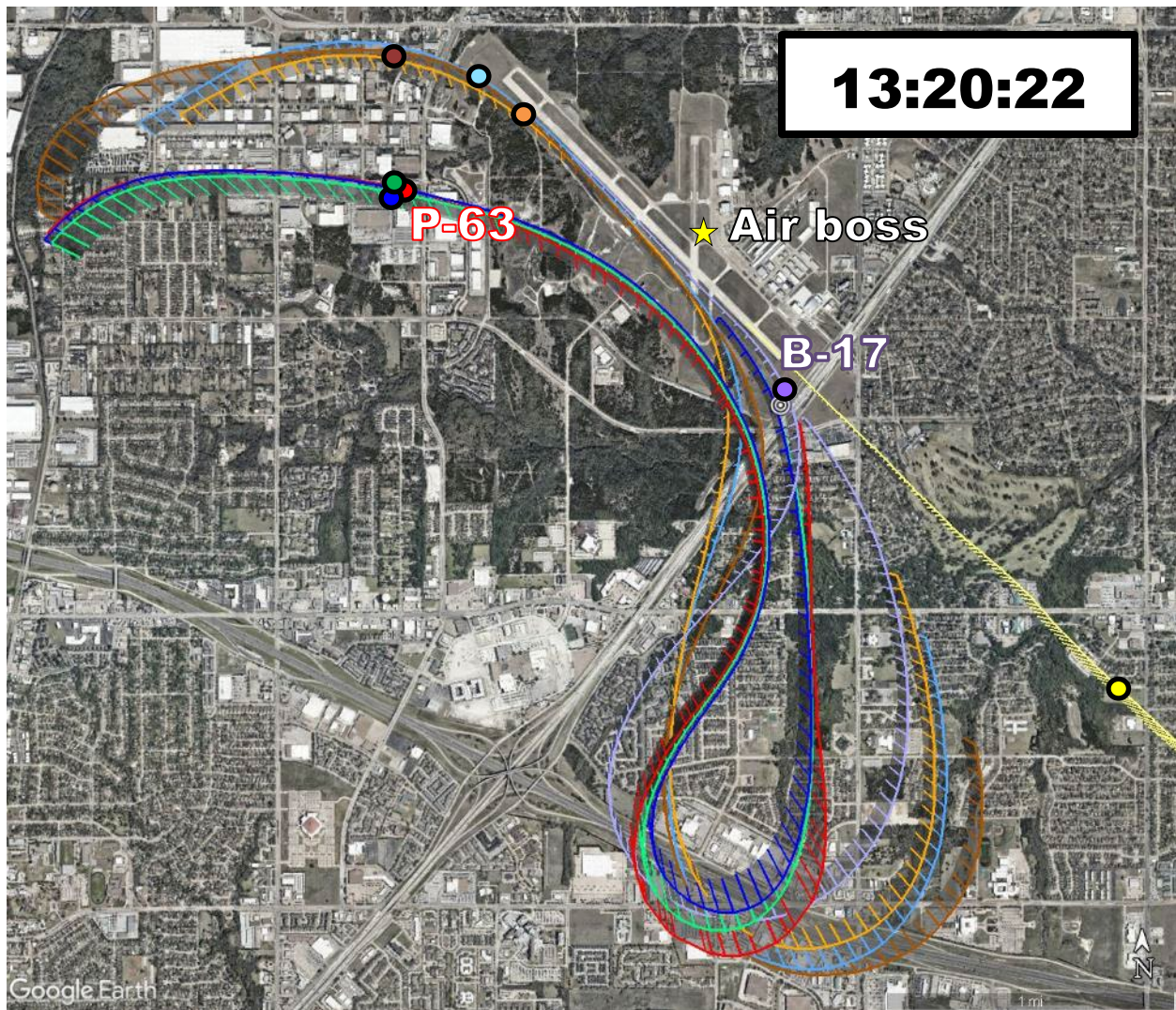
At 13:20:10, the lead P-51 responded “okay uh – say again for the fighters. That was not clear.” Figure 12 shows the locations of the airplanes at 13:20:10. At 13:20:14 the air boss stated “uh fighters go echelon uh – right go to echelon right” and the lead P-51 responded “okay fighters echelon right”.

<sup>1</sup> This was during a portion of the recording that could not be more accurately timed.



**Figure 12.** Position of airplanes at 13:20:10 is highlighted with a circle. The B-17 and P-63 are further labeled.

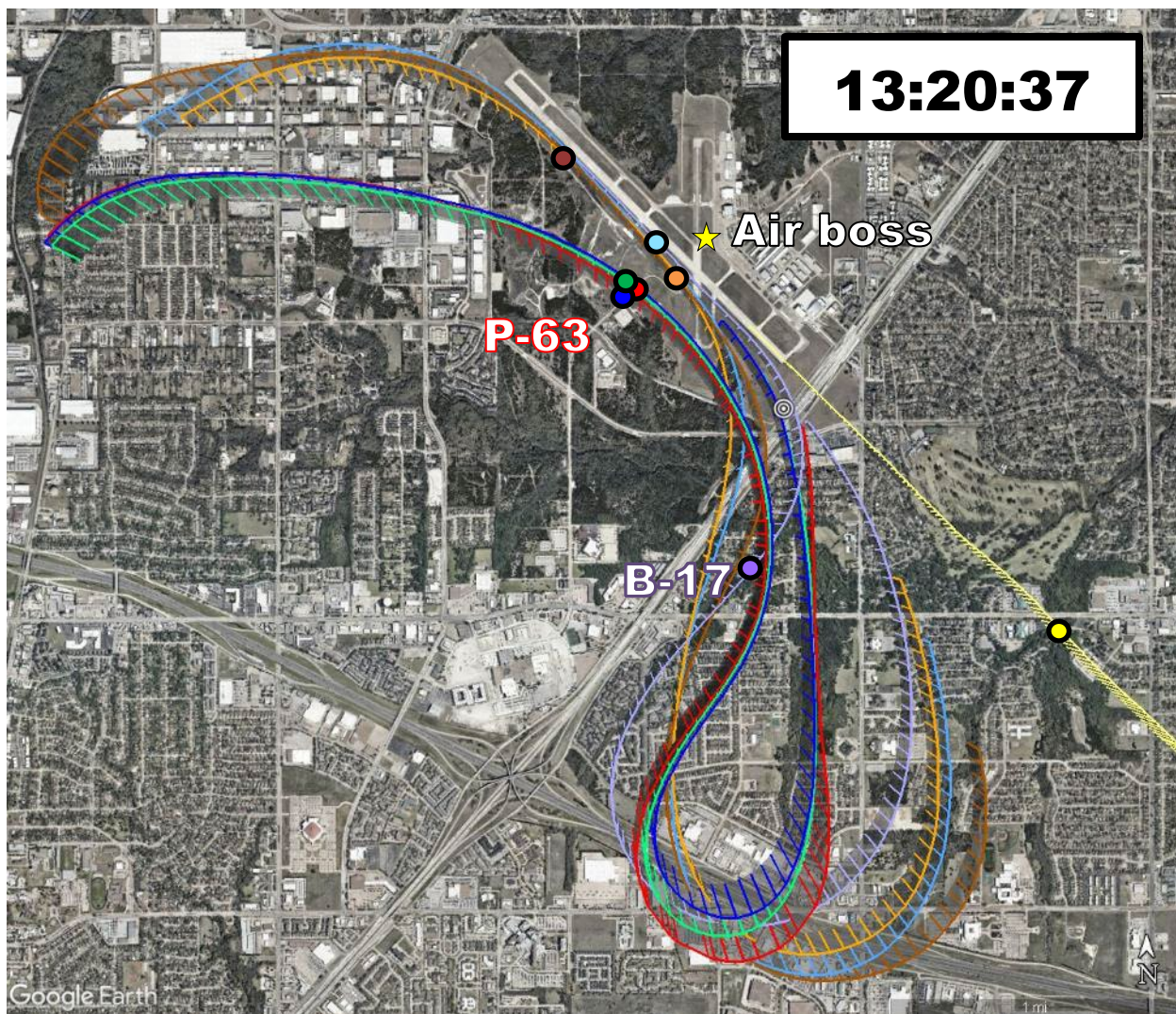
At 13:20:22 the air boss said “okay, B-24, if you could give me a couple of mi-uh - inches and close the gap I’d appreciate it. B-17 let’s keep the turn a little flat for me. Figure 13 shows the airplanes’ positions at 13:20:22. The B-24 was 1.3 miles behind the B-17 at this time. The Stearman is now visible in the lower right corner in yellow.



**Figure 13.** Position of airplanes at 13:20:22 is highlighted with a circle. The B-17 and P-63 are further labeled.

After an unintelligible transmission, the air boss communicated at 13:20:31 “Just a little bit. When you come back through you’re coming through on the thousand foot line”. The B-17 then responded “- roger”.

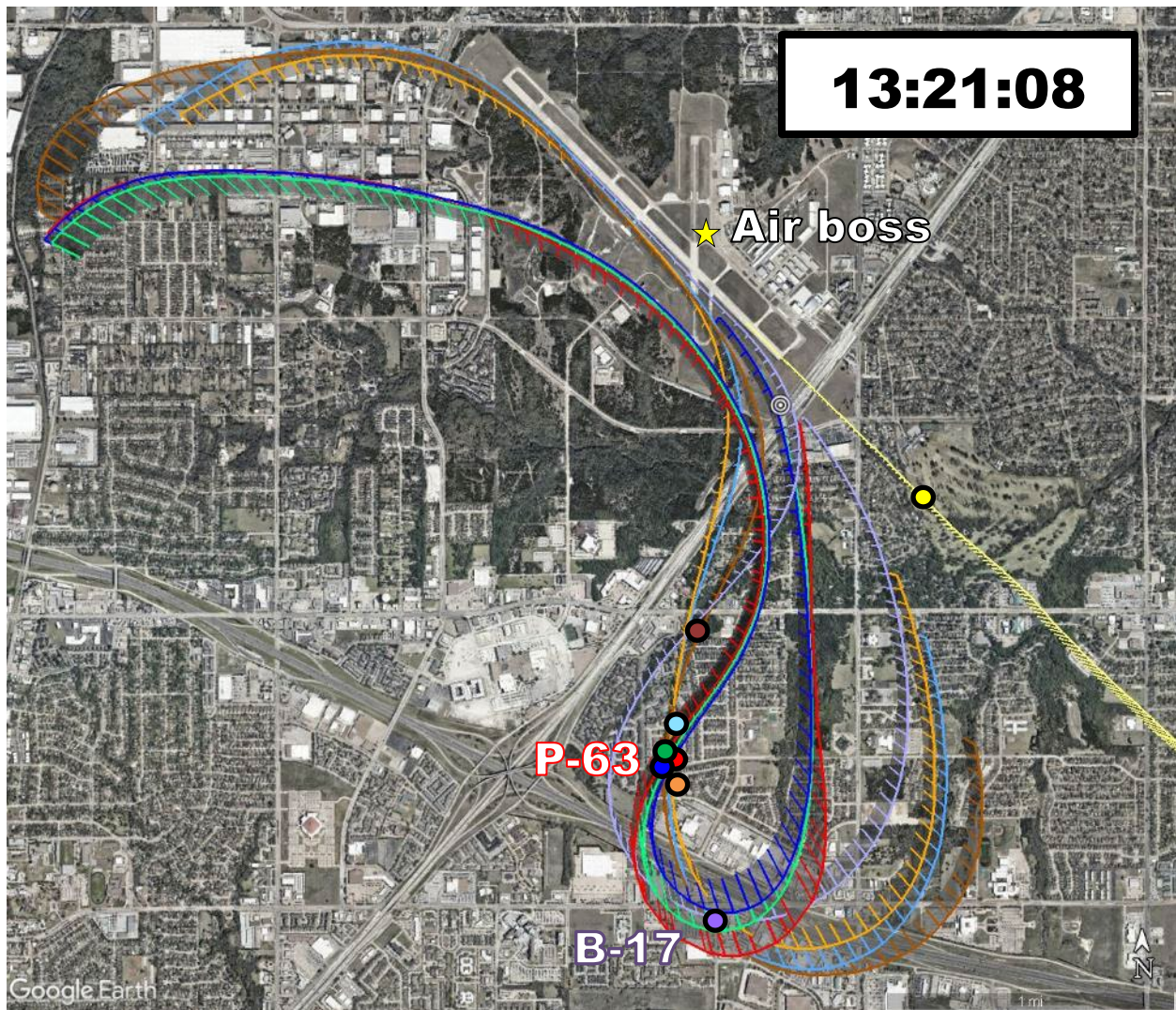
At 13:20:37 the air boss gave the instructions “American fighters should be in a right turn. You’re gonna follow the bombers out on a right ninety turn and then I’m going to roll you back in front of them.” Figure 14 shows the airplanes’ positions at 13:20:37. The fighters were behind the B-17 but abreast of the B-24 and SB-2C who were 500-600 ft lower than the fighters (see Figure 10).



**Figure 14.** Position of airplanes at 13:20:37 is highlighted with a circle. The B-17 and P-63 are further labeled.

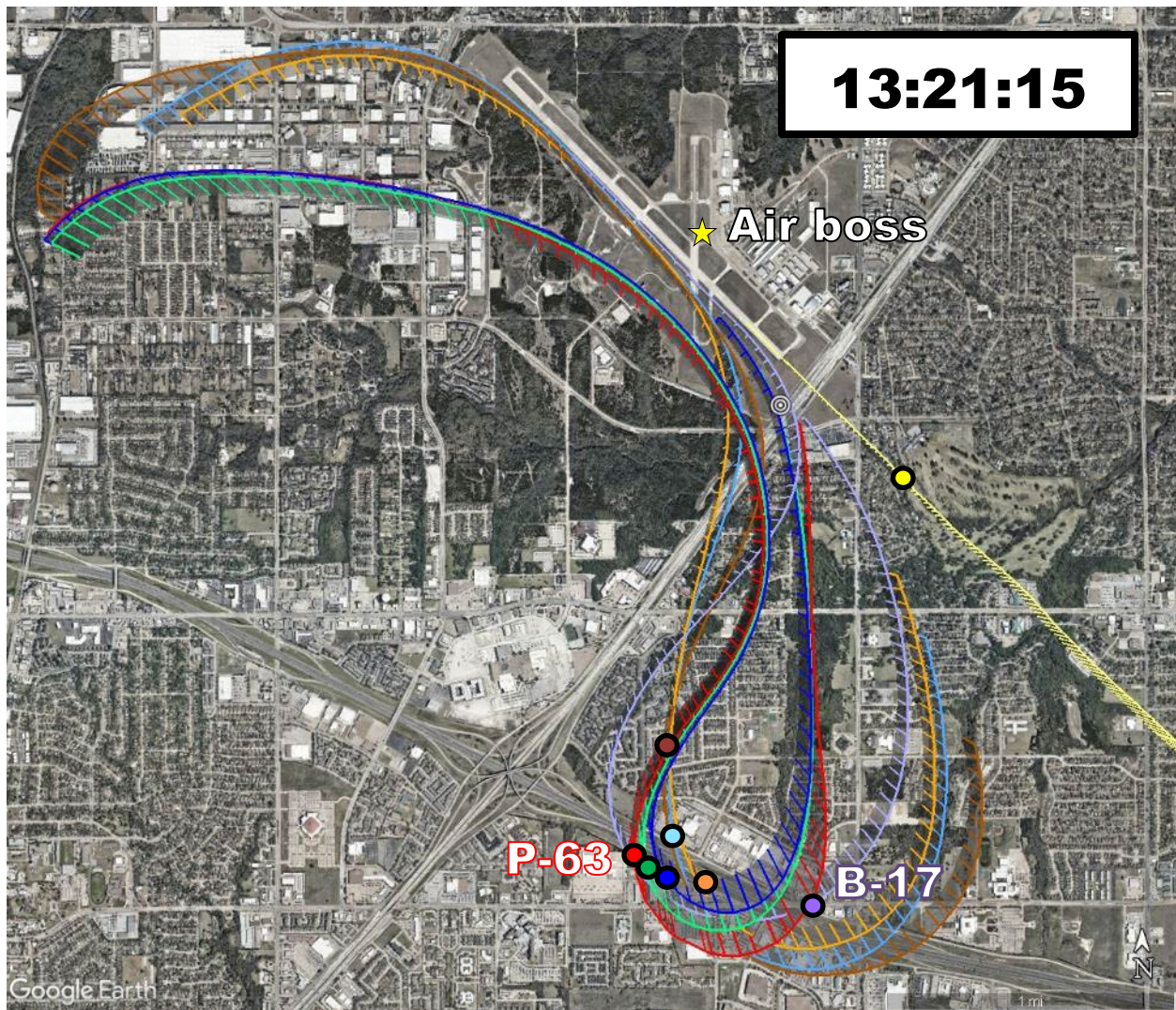
At 13:20:43 the air boss addressed the PT-17 with “Quebec, I need you to drop it down to the deck. Runway 3-1 clear to land.” The airplane continued to descend and landed seconds before the collision.

The air boss at 13:20:51 stated “there ya go B-17. Yup, gentle flat roll it around the thousand foot line” and the B-17 replied “thousand foot line for raiders”. The air boss continued at 13:20:58, “Fighters, roll it back to the left. Lead fighter lead roll it back to the left and y’all get in trail” to which the P-51 responded “okay, fighters in trail.” Continuing, the air boss stated “yeah and Gunfighter look out to your left side and find the B-17”. At 13:21:08 the lead P-51 replied “we see the B-17”. Figure 15 shows the airplanes’ locations at 13:21:08. The fighter group was passing over the B-24 and SB-2C. The B-17 was ahead and to the left.



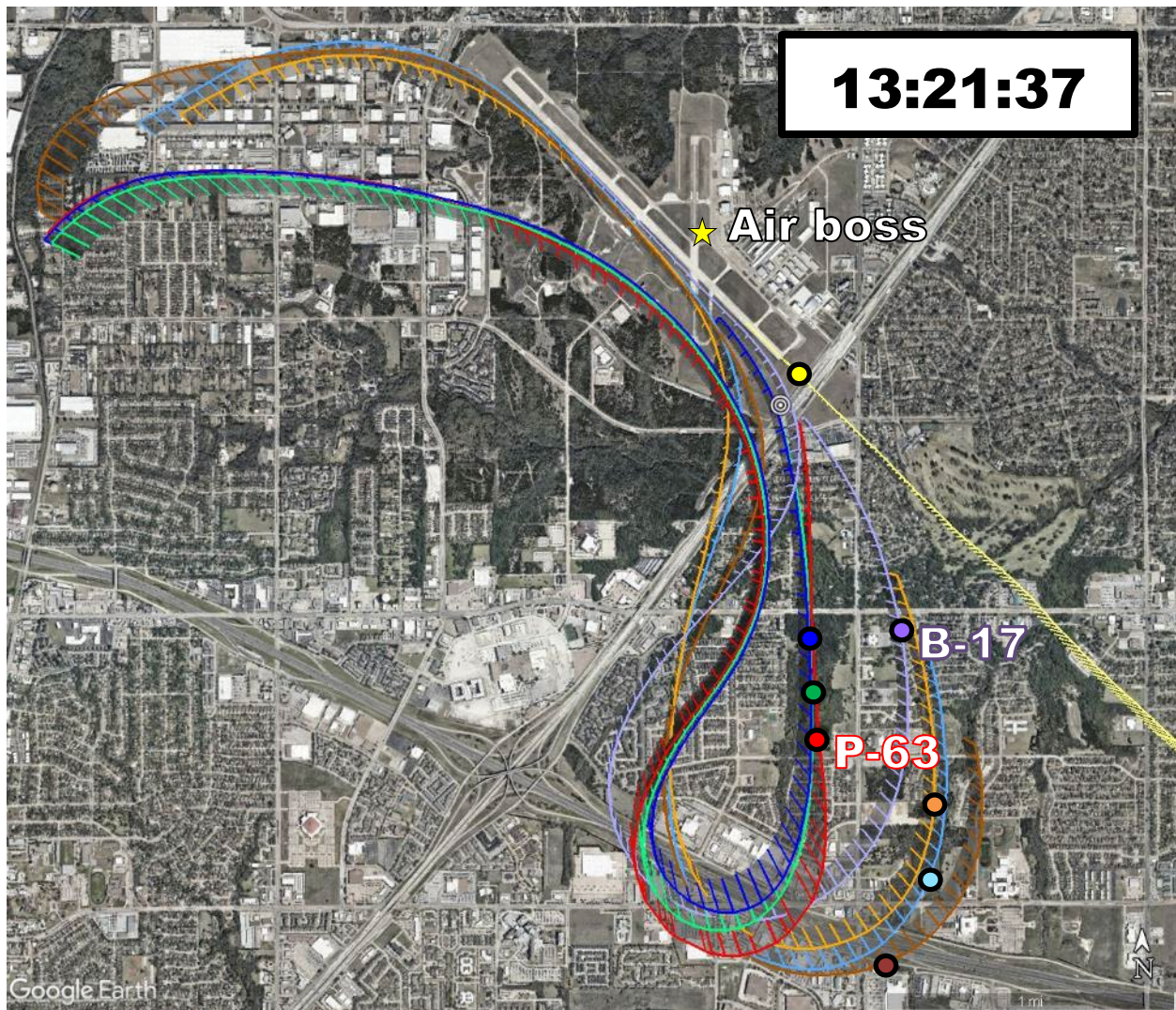
**Figure 15.** Position of airplanes at 13:21:08 is highlighted with a circle. The B-17 and P-63 are further labeled.

At 13:21:10 the air boss said “yeah, there ya go. Roll it back to the left. I want you to get in front of the bombers. I want you to come through on the outside edge of the runway” and at 13:21:15 the lead P-51 responded “okay”. Figure 16 shows the airplanes’ positions at 13:21:15. Notice the fighters had begun to spread out into an echelon formation as they climbed (see Figure 10).



**Figure 16.** Position of airplanes at 13:21:15 is highlighted with a circle. The B-17 and P-63 are further labeled.

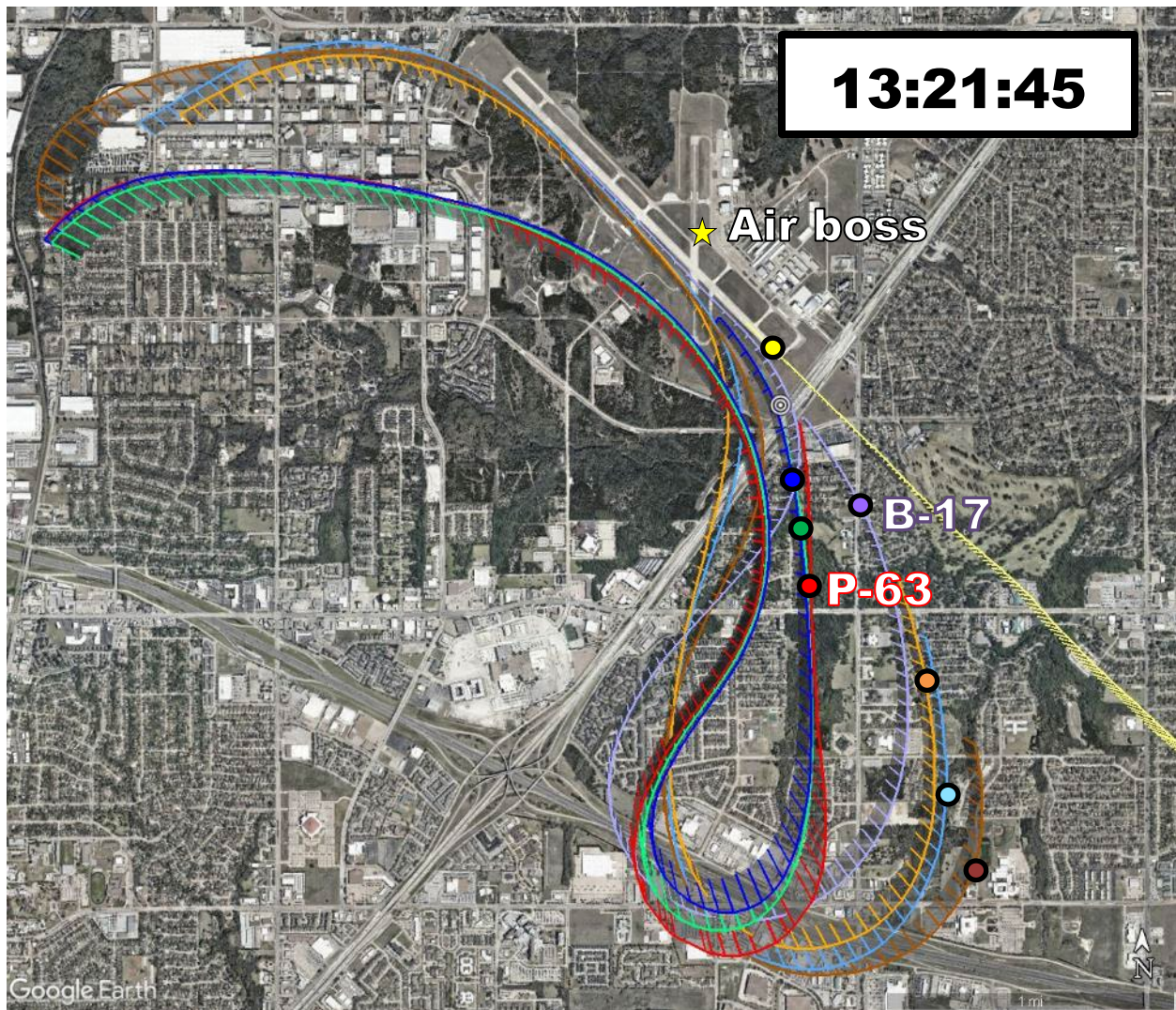
At 13:21:32 the air boss said “Nice job fighters you’re coming through first. That will work out. B-17 and all the bombers on the thousand foot line.” Figure 17 shows the B-17 was slightly ahead of the lead P-51 at 13:21:37.



**Figure 17.** Position of airplanes at 13:21:37 is highlighted with a circle. The B-17 and P-63 are further labeled.

Then at 13:21:39 “B-17 you got the fighters in front of you off your left?” There followed an unintelligible transmission from an unknown source. The lead P-51 was just pulling ahead of the B-17 as discussed in the Flight Path section.

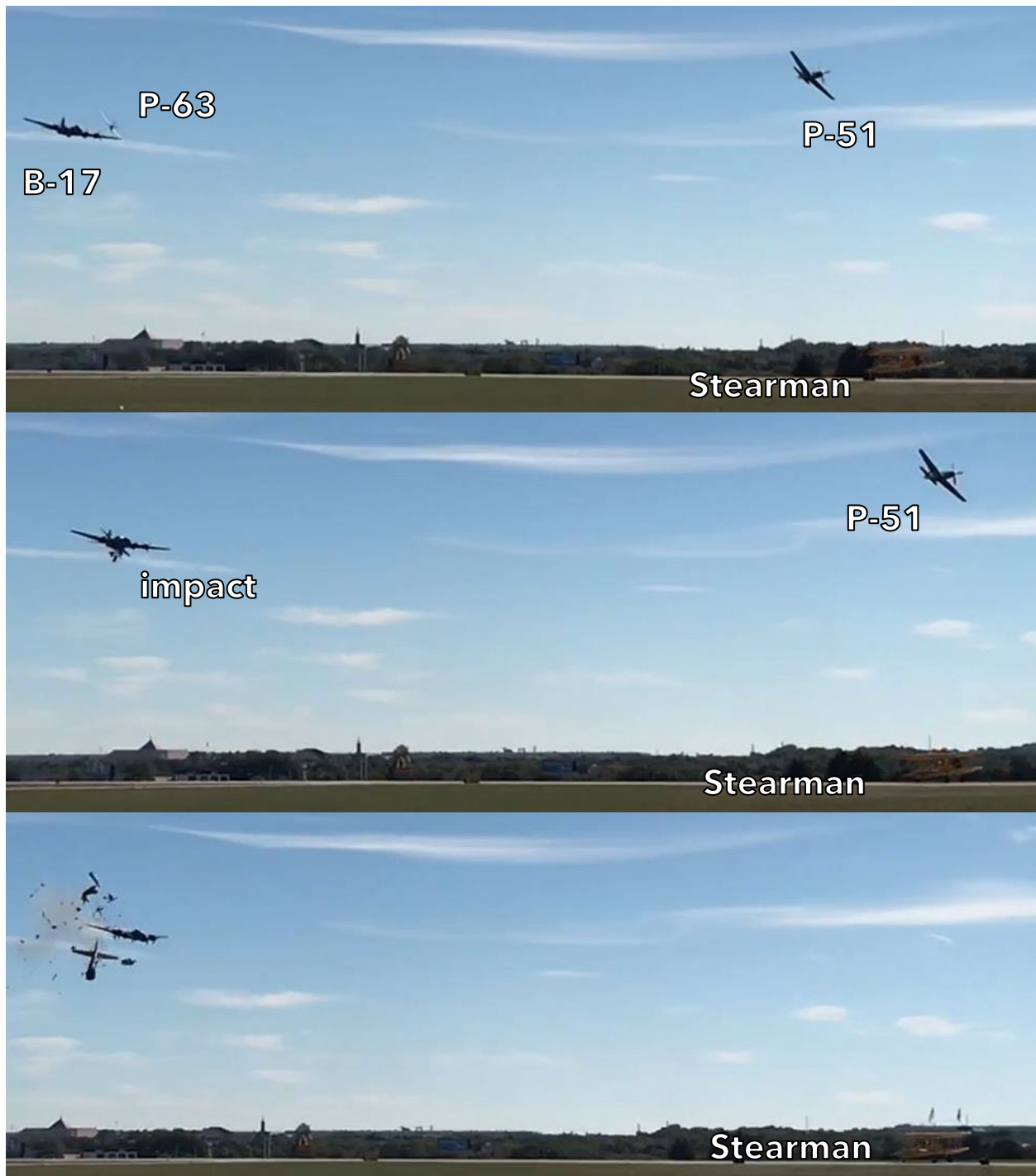
At 13:21:45 the air boss said “Nice job fighters, come on through” and continued “Fighters will be a big pull up and to the right.” All three fighters were still descending (Figure 10). Figure 18 shows the airplanes’ positions at 13:21:45. The lead P-51 was ahead of the B-17, the second P-51 pulling up alongside, and the P-63 was behind. The Stearman was over the displaced threshold to runway 31.



**Figure 18.** Position of airplanes at 13:21:45 is highlighted with a circle. The B-17 and P-63 are further labeled.

ADS-B data ended for the B-17 and P-63 at 13:21:53, just before the collision. The final ADS-B points are approximately 150 ft apart and 400 ft from the point of collision determined from the Video Study which will be discussed further in section 7.0 Visibility Simulation. After the collision the air boss communicated “knock it off. Knock it off. Roll the trucks. Roll the trucks. Roll the trucks. Knock it off. Roll the trucks”.

Figure 19 shows three images from the collision sequence from a witness in the crowd (see Figure 3). The second P-51 is visible in the first two images. The Stearman is visible in all three images (faintly in yellow) on its landing roll on runway 31.

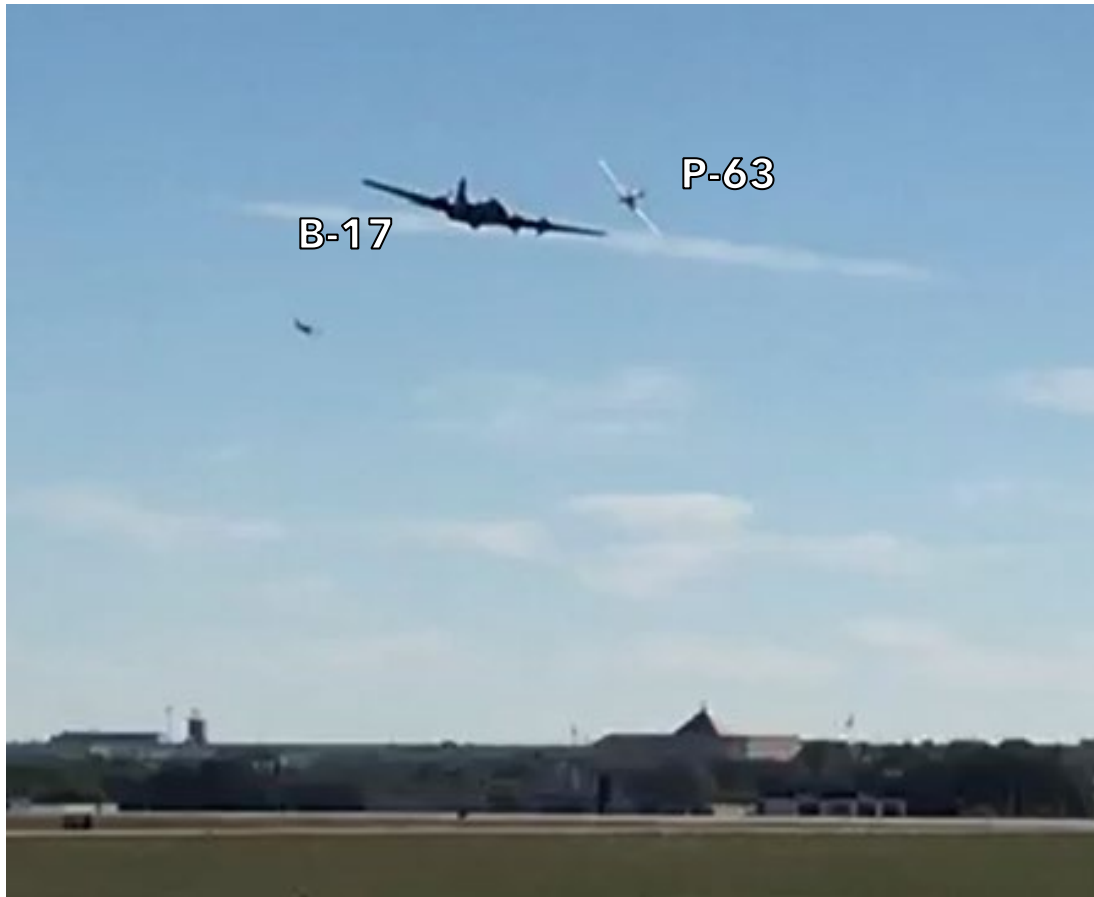


**Figure 19.** Video stills of collision sequence. These images show the B-17, P-63, the second P-51, and the landing Stearman.

## 7.0 Visibility Simulation

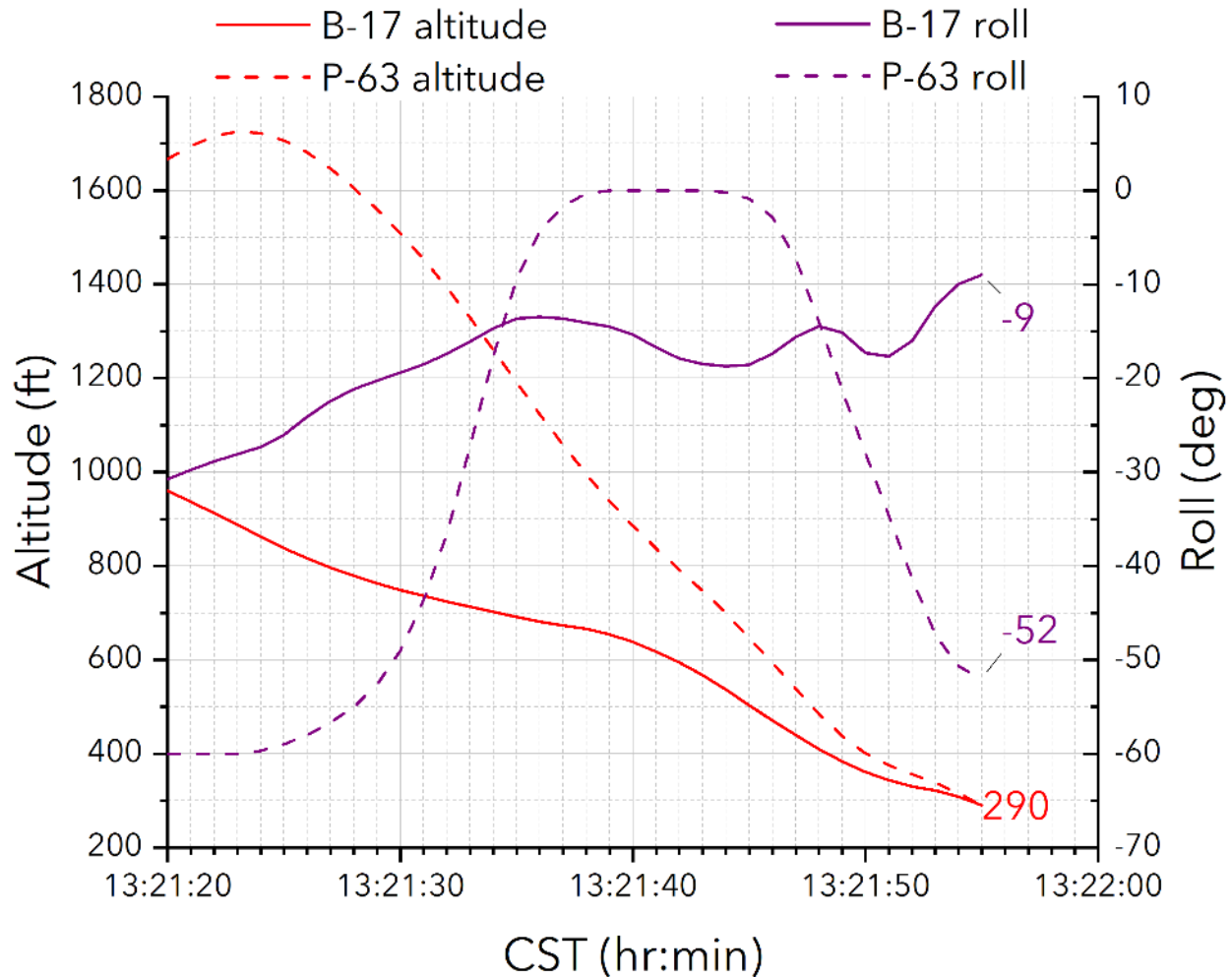
Of interest was the visibility of the P-63 and B-17 from each airplane. This visibility study used Microsoft Flight Simulator X (FSX) and simulated the flights of the

B-17, P-63, and two P-51s from time 13:21:20 until the end of flight. The attitudes of the B-17 and P-63 were calculated from the ADS-B flight path using simplified aerodynamic models. The Video Study used videos of the collision to determine the attitudes of the airplanes for the final second before impact. The calculated and measured angles were combined and smoothed to recreate the flight path and attitude of the P-63 and B-17.



**Figure 20.** Video still of the B-17 and P-63 just before impact.

Figure 21 shows the altitudes and roll angles of the B-17 and P-63 used for the visibility study. The final roll angles of the airplanes are consistent with videos and photos of the accident airplanes just before impact.



**Figure 21.** Altitude above ground and roll for the B17 and P63 for the final 35 seconds of flight.

## 7.1 P-63 Interior view

The P-63 is a single-seat airplane. Figure 2 and Figure 22 show that the seat back is approximately in line with the rear of the side window. What a pilot can and cannot see from the cockpit of the airplane is dependent on the pilot's stature and positioning in the airplane. A taller or shorter pilot or leaning forward versus sitting back will change how the airplane structure obscures the view of the outside. Figure 2 shows that pilot's eyes were level with the upper frame and in the front-to-back center of the side window. This indicates that much of the side window would be in the pilot's peripheral vision or might require a turn of the head.



**Figure 22.** Exemplar P-63 cockpit interior.

Figure 23 shows the cockpit view of the exemplar P-63 in FSX. The view includes some of the side window, the front, and out the overhead portion of the canopy.



**Figure 23.** Exemplar P-63 cockpit interior in Microsoft Flight Simulator. Window terminology for this report is shown.

## 7.2 P-63 Visibility Simulation

The airplanes' flight paths and attitudes were used to drive an FSX recreation of the accident. Representative models of a P-63, a B-17, and two P-51s were used to simulate what the P-63 pilot may have had the opportunity to see during the final 23 seconds of flight. As discussed in the last section, a pilot's actual view is based on individual stature and positioning in the airplane. Additionally, visual acuity and focus greatly affect what is visible. On average, in ideal conditions, a person can see an object that spans at least  $0.01^\circ$  of their field of view when looking directly at the object [3]. This is influenced further by the person's age and focus, the contrast of the object with the background, color, and illumination.

The B-17 model selected for this simulation was colored the same as the accident airplane: olive drab above and neutral gray below with red wingtips and tail. During World War II the olive drab and gray paint scheme was used to camouflage airplanes. The olive drab blends in with the ground when viewed from above and the gray with the sky when viewed from below.

The FSX background roughly approximated the landscape of the area. In Figure 23 the golf course and housing areas visible in Figures 5, 6, and 9 are seen. The following discussion will highlight the other airplanes as they come into the view area, but often the airplanes are difficult to discern against the background and will be circled. The B-17 can be difficult to discern against the background even when larger due to its camouflaged coloration.

The simulation began at 13:21:20. From 13:21:22 to 13:21:24 (Figure 24) the B-17 was in view, but very small, passing from the upper left of the P-63 canopy to behind the left side of the nose. The airplanes were approximately 0.6 miles apart.



**Figure 24.** View of B-17 (circled in red) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:24.

By 13:21:28, the lead P-51 became visible in the upper left of the canopy as shown in Figure 25 but again was small. The second P-51 was also visible in the left window.



**Figure 25.** View of the lead P-51 (circled in yellow) and second P-51 (circled in green) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:28.

As discussed in the previous section, the air boss communicated “Nice job fighters, you’re coming through first. That will work out. B-17 and all Bombers on the thousand-foot line” at 13:21:32. The B-17 appeared in the lower right-side window by 13:21:34 while the lead P-51 moved into the center front windshield. Notice the view of the P-63 interior in Figure 26 has been pulled back and turned to the right so that both airplanes are visible. It was likely that the right window was mostly in the pilot’s peripheral vision. An inset expanded view of the B-17 is shown so the coloration of the airplane versus the simulated background can be seen more clearly.



**Figure 26.** View of the lead P-51 (circled in yellow) and B-17 (circled in red) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:34. The inset shows a magnified view of the B-17, which also includes an FSX annotation that aids in finding the location of the airplane.

By 13:21:38 the lead P-51 was above the horizon in the center windshield. This position against the sky would have made the P-51 significantly more visible to the pilot. The B-17 was in the back half of right window and remained in that position, increasing in size. At 13:21:45 the air boss said “nice job fighters, come on through” and at 13:21:47 (Figure 27), the second P-51 became visible in the left front windshield. The lead P-51 was visible in the upper left of the canopy.



**Figure 27.** View of the lead P-51 (circled in yellow), the second P-51 (circled in green) and B-17 (circled in red) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:47.

At 13:21:48 the air boss gave additional instructions of “fighters will be a big pull up and to the right” as the P-63 rolled left and the position of the B-17 began dropping to the bottom of the right window. The P-51s remained in the upper left of the front view. The B-17 remained visible until 13:21:50 when it disappeared below the window frame. Both P-51s were visible through the canopy.



**Figure 28.** View of the lead P-51 (circled in yellow), the second P-51 (circled in green) and B-17 (circled in red) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:50. This is the final view of the B-17 from the P-63.

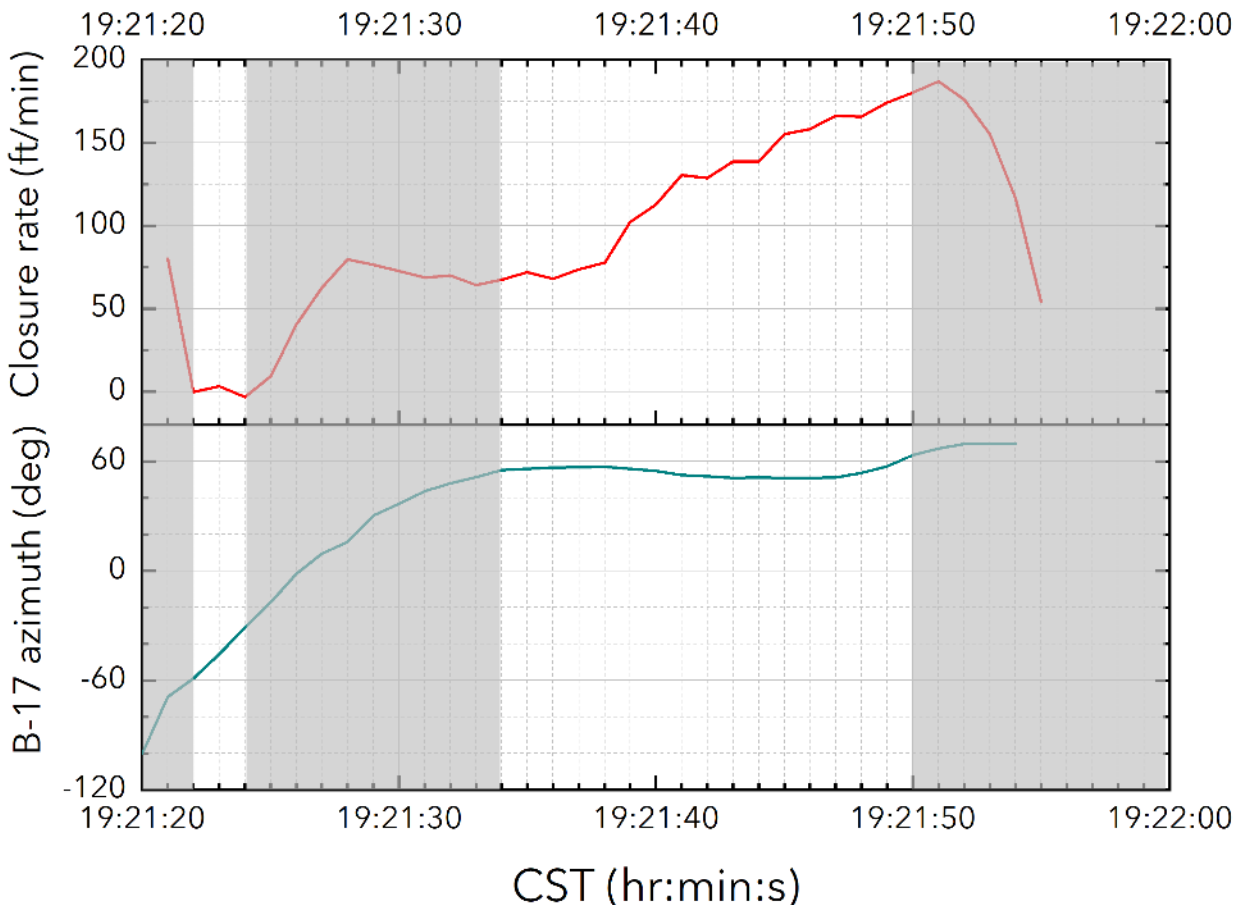
At impact, four seconds later, the B-17 was not visible to the P-63 in this simulation.

### 7.3 Separation Calculations

In addition to the factors discussed in 7.2, relative motion of the object in a person's field of view affects whether the object is perceived. An object that moves with the observer such that it remains stationary in their view is less likely to be perceived compared to an object that is moving in the field of view.

Figure 29 shows the calculated closure rate (how quickly the airplanes were moving towards each other) and the azimuth angle of the B-17 to the P-63. Gray shaded areas are when the B-17 was obscured by the structure of the P-63 in the FSX simulation. The first two seconds of visibility correspond with Figure 24 when the B-17 was visible in the front window of the P-63. The azimuth angle was changing, but the closure rate was near zero, indicating that the airplane moved through the field of view but did not change size. The second period of visibility corresponds with Figure 26 -

Figure 28 when the B-17 was visible in the right side window of the P-63. Figure 29 shows how the B-17 had little relative motion out the right side window of the P-63 as its azimuth angle showed little change. The closure rate was increasing consistent with the increasing size of the B-17 in the visibility simulation.



**Figure 29.** Closure rate and azimuth angle for the P-63 to the B-17. Gray shaded areas are when the B-17 was obscured by the structure of the P-63.

#### 7.4 B-17 Interior view

A view of the pilot's side of an exemplar B-17 is shown in Figure 30 and can be compared to Figure 1. The pilot's seat back is even with the division between the forward and aft left side windows. Figure 31 shows the view from the cockpit of the FSX B-17 model. The aft side window is not visible unless the view is turned such that the front windshield is not in view.



**Figure 30.** View from a panorama image of an exemplar B-17.



**Figure 31.** Forward view from the pilot's seat of exemplar B-17 cockpit interior in Microsoft Flight Simulator. The view must be turned to the left to see out the aft side window.

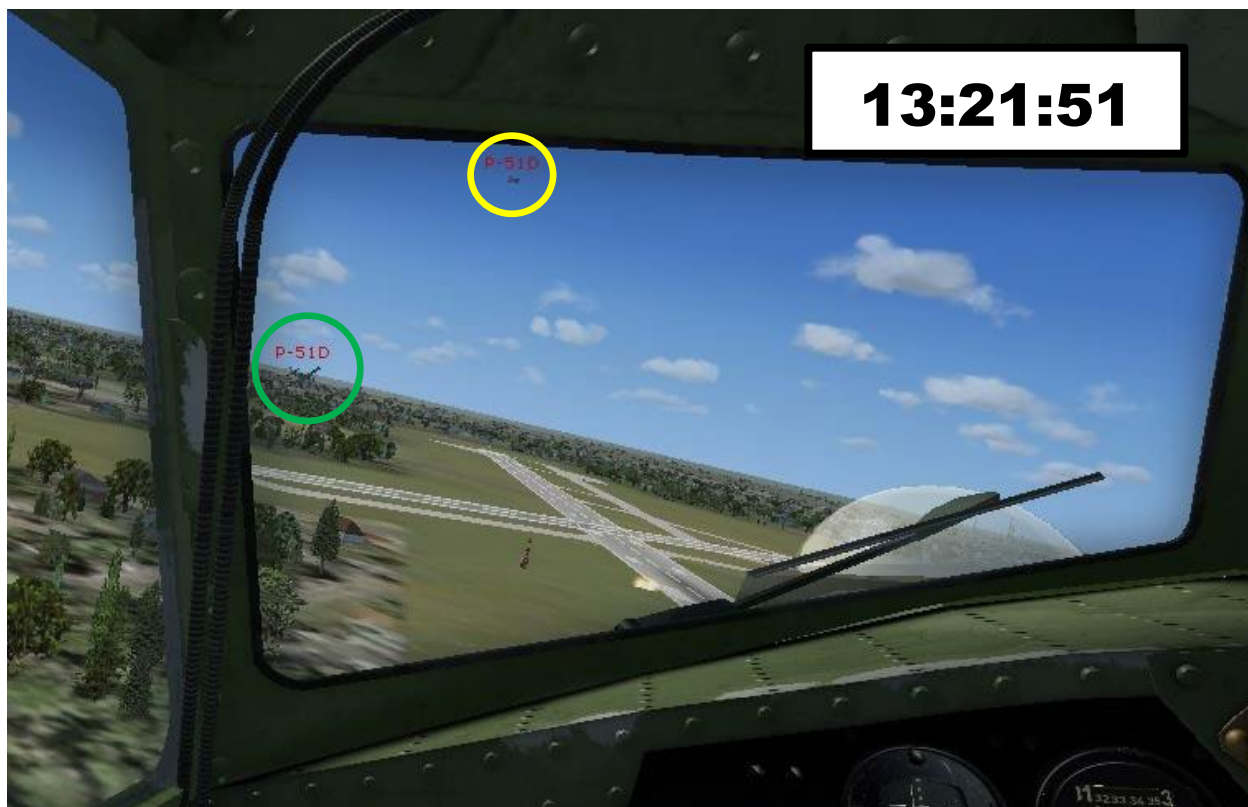
## 7.5 B-17 Visibility Simulation

At 13:21:39 the air boss asked “B-17 you got the fighters in front of you off your left?” The view shown in Figure 32 was turned all the way to the left and the left wing and engine of the B-17 can be seen. The lead P-51 and second P-51 were in view through the forward side window and the P-63 was visible through the aft side window, behind the pilot’s left shoulder.



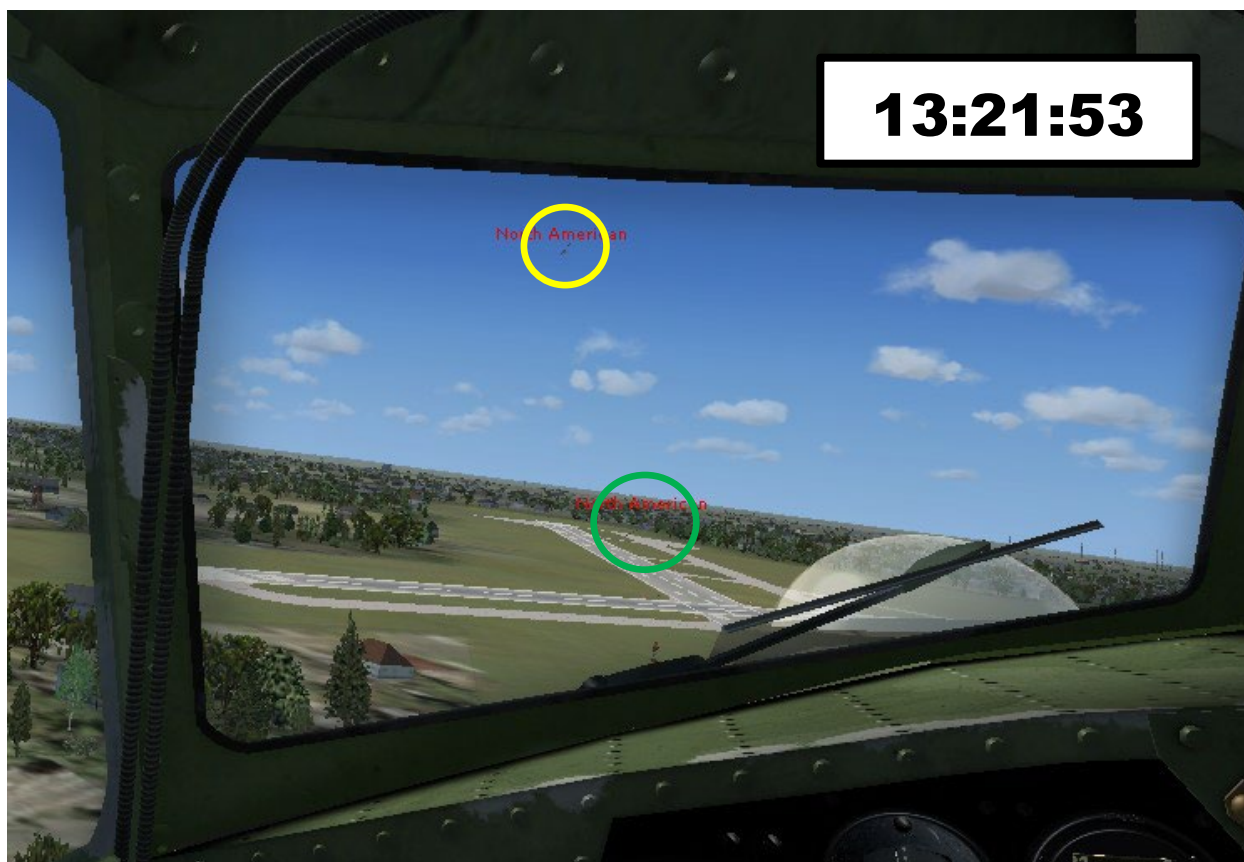
**Figure 32.** View of the lead P-51 (circled in yellow), second P-51 (circled in green, and P-63 (circled in red) from exemplar B-17 cockpit interior in Microsoft Flight Simulator at 13:21:39.

The fighters moved forward in the B-17’s view, but the P-63 was obscured by the pillar between the forward and aft side window from 13:21:44 on. This may not be representative of the accident pilot’s view, but no cockpit view in FSX could see the P-63 until near the end of flight. The lead P-51 was visible through the front windshield by 13:21:49 and the second P-51 by 13:21:51 as shown in Figure 33.



**Figure 33.** View of the lead P-51 (circled in yellow) and the second P-51 (circled in green) from exemplar B-17 cockpit interior in Microsoft Flight Simulator at 13:21:51.

In the FSX simulation, the P-63 was not visible at 13:21:52, three seconds before impact. It became rapidly visible behind the left wing during the final seconds of flight (Figure 35). The P-51s were both visible through the front windshield (Figure 34).



**Figure 34.** View of the lead P-51 (circled in yellow) and the second P-51 (circled in green) from exemplar B-17 cockpit interior in Microsoft Flight Simulator at 13:21:53.



**Figure 35.** View of the P-63 from exemplar B-17 cockpit interior in Microsoft Flight Simulator at 13:21:53.

In the FSX simulation, the P-63 impacted the B-17 behind the left wing, consistent with videos and photographs of the collision.

#### **D. SUMMARY**

During the lead up to the collision, eight airplanes were participating in the airshow as a group of three fighter airplanes and five bombers. The B-17 was the lead airplane of the bomber group, and it took off at 13:10:30 to be followed by the other bomber airplanes. The bomber group flew at altitudes between 200 ft and 500 ft agl along the show line and between 700 ft and 1,000 ft in the turns. Airspeed varied between 120 kts and 190 kts. The lead P-51 of the fighter group took off at 13:14:30 and the fighter group flew in close formation at an average altitude of 1,000 ft agl. The fighter group's airspeeds were between 150 kts and 175 kts. The fighter group joined in behind the bomber group flying up the 1,000 ft line at about 13:18:50.

Approximately two minutes before the collision, the air boss gave instructions that the fighter group should accelerate and turn in front of the bomber group and fly

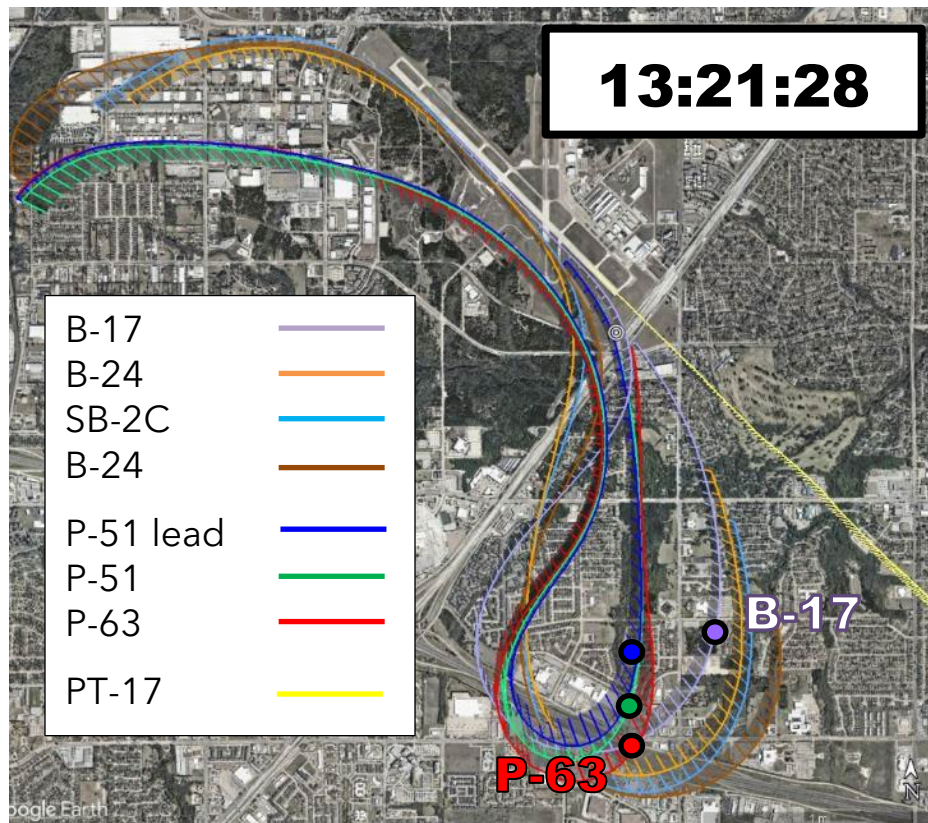
the 500 ft line along runway 31 while the bomber group flew after them up the 1,000 ft line. After some uncertainty about the instructions, the fighter group climbed to 1,500 ft during their final right 90° turn. Then, during the left 270° turn, the fighters descended from this altitude to accelerate from 150 kts to 230 kts and began to turn onto the 1,000 ft show line. The lead and second P-51 were able to pass the lead B-17, but the P-63 impacted the B-17 behind its left wing.

A visibility study determined that the B-17 was visible from the P-63 from 13:21:34 to 13:21:50, but was likely blocked from view from 13:21:50 up to the collision at 13:21:54. The location of the B-17 in the right-side window away from the direction of travel and the two P-51's ahead, its small size, lack of relative motion, and camouflage coloring may have made perception of the airplane more difficult. As the P-63 continued to turn left towards the runway show lines, the B-17 moved out of view for the final few seconds of flight.

## **E. REFERENCES**

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2. Air boss Airshow Audio Recording, Factual Report, CEN23MA034, National Transportation Safety Board, 2023.
3. Velasco e Cruz, A. *Historical Roots of 20/20 as a (Wrong) Standard Value of Normal Visual Acuity*, Optometry and Vision Science Journal, Vol. 67, No.8, p. 661, March 30, 1990. Copyright © American Academy of Optometry.

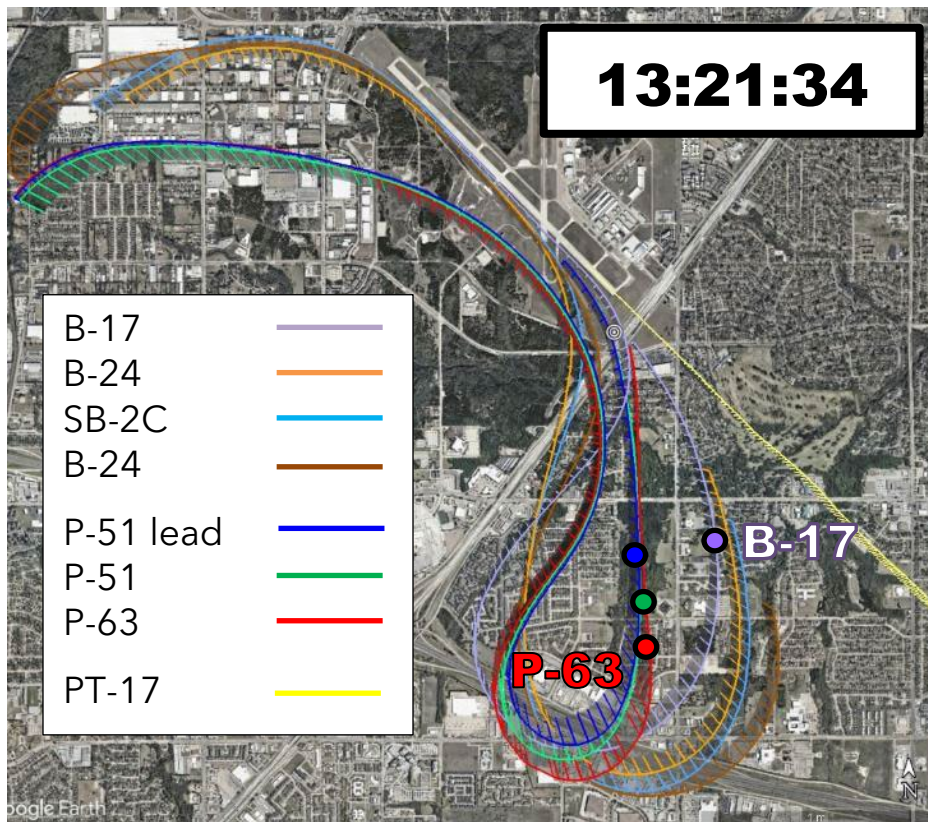
## F. APPENDIX



**Figure 36.** Position of P-51s, P-63, and B-17 at 13:21:28.



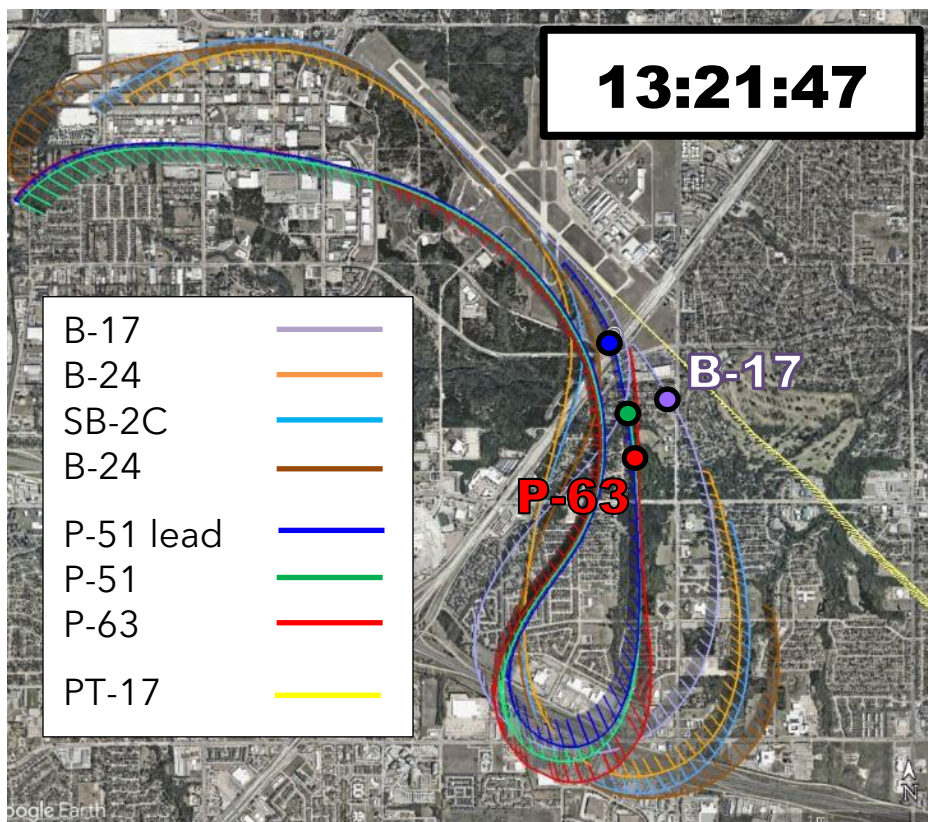
**Figure 37.** View of the lead P-51 (circled in yellow) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:28.



**Figure 38.** Position of P-51s, P-63, and B-17 at 13:21:34.



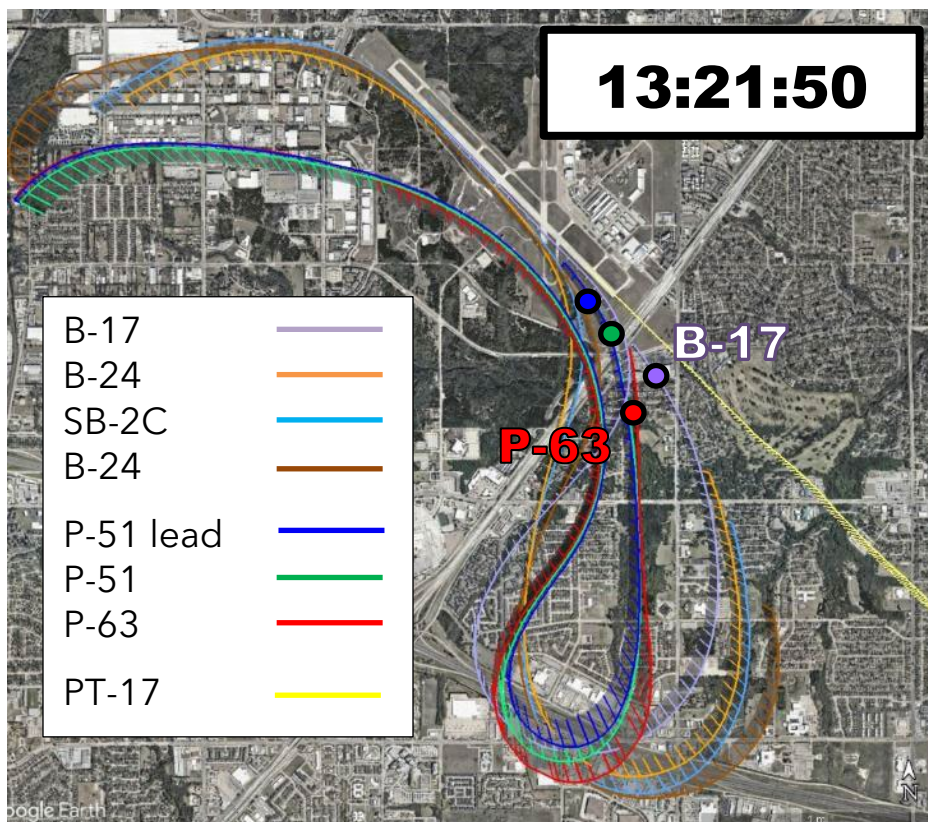
**Figure 39.** View of the lead P-51 (circled in yellow) and B-17 (circled in red) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:34.



**Figure 40.** Position of P-51s, P-63, and B-17 at 13:21:47.



**Figure 41.** View of the lead P-51 (circled in yellow), the second P-51 (circled in green) and B-17 (circled in red) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:47.



**Figure 42.** Position of P-51s, P-63, and B-17 at 13:21:50.



**Figure 43.** View of the lead P-51 (circled in yellow), the second P-51 (circled in green) and B-17 (circled in red) from exemplar P-63 cockpit interior in Microsoft Flight Simulator at 13:21:50. This is the final view of the B-17 from the P-63.