NATIONAL TRANSPORTATION SAFETY BOARD
Vehicle Recorder Division
Washington, D.C. 20594

August 3, 2012

Image Study

Specialist's Study Report
By Christopher Babcock

1. EVENT SUMMARY

Location: Reno, Nevada
Date: 09/16/2011
Aircraft: P-51D
Registration: N79111
Operator: Aero-Trans Corporation
NTSB Number: WPR11MA454

On September 16, 2011, about 1626 Pacific Daylight Time, an experimental single seat North America P-51D, registration N79111, collided with the airport ramp in the spectator box seat area following a loss of control while maneuvering during an unlimited class gold heat race at the National Championship Air Races at Reno Stead Airport (RTS), Reno, Nevada. The airplane was registered to Aero-Trans Corp, Ocala, Florida, and operated by the pilot as Race 177, the *Galloping Ghost*, under the provisions of *Title 14 Code of Federal Regulations* (CFR) Part 91. The commercial pilot and 10 people on the ground sustained fatal injuries; more than 60 people were treated for minor to serious injuries. The airplane fragmented upon impact with the ramp. Visual meteorological conditions prevailed, and no flight plan had been filed for the local air race flight, which departed RTS about 10 minutes before the accident.

A number of still photo and video files captured by witnesses were transmitted to the National Transportation Safety Board's Vehicle Recorder Laboratory for evaluation.

2. GROUP

A group was not convened

3. DETAILS OF INVESTIGATION

The race was well documented by still and video cameras from various positions on the race course. A large amount of still images and videos were provided to NTSB investigators. Each photo and video was evaluated to determine its potential value to the investigation. After review of the images and video, several areas were identified for further investigation:

- Documentation of the loss of control sequence (including control surface positions)
- Determination of elevator and elevator trim tab deflections during the course of the flight

- Documentation of structural deformation of the fuselage
- Correlation of image information to recorded telemetry data[1]

3.1. Time Correlation and Alignment

In order to precisely determine the sequence of events that led to the accident the critical witness videos and photographs were time aligned. GPS time, adjusted to the local PDT, as recorded on the telemetry ground station was chosen as the time base. Common events were identified within the photographs and videos to align them to GPS time. According to the Video Study, 2:44.87 (m:ss) elapsed time in the Schillereff video corresponds to 16:24:31.00 PDT. This video showed the precise time of the loss of the left trim tab occurred at 2:47.37 (m:ss) elapsed time, or 16:24:33.50 PDT (Figure 1). Figure 2 shows the departure of the trim tab at the same instant from the Kirchenbauer camera. According to the time extracted from the Exif[2] data from Figure 2, 7.3 seconds should be subtracted from all images from the Kirchenbauer camera to adjust to local PDT time. Exif data from this camera only recorded seconds to a single decimal place.

Figure 1. Trim tab departs in video.

Figure 2. Trim tab departs in photograph.

According to the video the tail wheel extended at 16:24:30.20 PDT ±0.10 second due to some blurred frames (Figure 3). Figure 4 shows the wheel just beginning to extend at 17:23:25.94 according to the Exif data from the Apfelbaum camera. Exif times attached to images from the Apfelbaum camera times should be decremented by 58:55.74 (mm:ss) to adjust to local PDT time.

[1] See Telemetry Specialist's Factual Report
[2] Exchangeable image file format data contains information such as time, date, camera type, shutter speed, etc, embedded into the image file as metadata

Figure 3. Video frame showing tail wheel extending.

Figure 4. Photo showing tail wheel extending.

Images from the Ranney camera were also time correlated. Figures 5 through 9 show a sequence combining images from the Ranney camera and time correlated images from the Kirchenbauer camera to place the Ranney images in time. The Ranney images in Figures 6-8 all have an Exif time stamp of 16:24:45. Exif data from this camera is only recorded to the nearest second. All images from the Ranney camera should be decremented by 12 seconds to adjust to local PDT time within one second.

Figure 5. Just prior to tab separation at 16:24:32.3 PDT.

Figure 6. Trim tab begins to separate.

Figure 7.

Figure 8.

Figure 9. Trim tab separates at 16:24:33.5 PDT

3.2. Pre-accident Elevator and Trim Tab Angle

The owner/pilot of the aircraft made several modifications to the pitch control system as he prepared to race at Reno. One of the modifications entailed disconnecting the right elevator trim tab and locking it in a fixed position faired with the elevator. The left elevator trim tab remained controllable by the pilot, but with an electric actuator rather than the original manual system. Photographs of the aircraft during previous flights and the first three incident-free laps of the accident flight were examined in order to determine the deflection of the elevator and left elevator trim tab for input into the aircraft performance model.

Figure 10 shows a cropped image of the rear of the aircraft in the “Valley of Speed” portion of the race course between pylons 6 and 7 during the aircraft’s second flight on September 13, 2011. It is zoomed in on the left tab deflected trailing edge up. Although it is not possible to determine on which lap this image was taken, telemetry data recorded indicate

the aircraft was travelling between 360-380 knots groundspeed at this point on the course during all laps from that flight.

Scaling the aircraft based on the known length of the horizontal stabilizer, 12 feet, a direct measurement was taken of the trailing edge displacement (*d'*) of the trim tab with respect to the elevator. No correction was necessary at this point as the camera was directly aligned with the longitudinal plane of the aircraft. A correction was necessary to correct for the foreshortening effect due to the relative pitch angle of the aircraft with respect to the camera image plane (*θ*). An ellipse was overlaid onto the propeller arc. Comparing the measured major axis of the ellipse to the known propeller diameter (11'2") and the known vertical angle between the thrust vector and longitudinal axis (+1.75°), the relative pitch angle of the aircraft with respect to the image plain can be found (Figures 10-11). An increment of 0.91° was added to the relative pitch angle to account for the 0.91° incidence angle between the longitudinal axis and the horizontal stabilizer.[3] The elevator angle was assumed to be near zero as observed in other photos of the aircraft transiting the Valley of Speed. Camera distortion was assumed to be zero as the telephoto zoom of the camera lens tends to minimize barrel distortion. Figure 12 shows the dimensioned photograph.

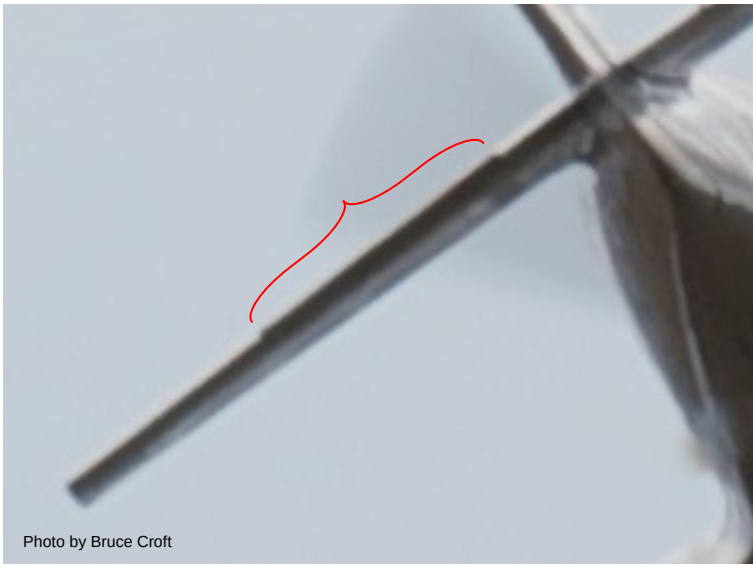
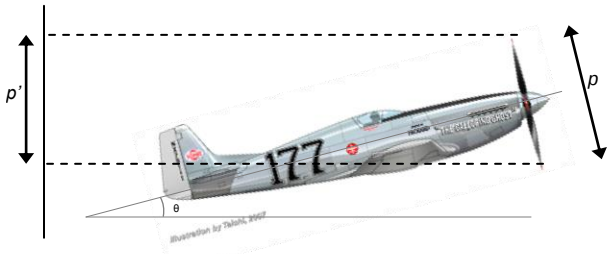


Figure 10. Cropped photo showing trim tab deflected upward.



$$\theta = \cos^{-1}\frac{p'}{p} - 1.75^{\circ}$$

Figure 11. Geometry of aircraft pitched relative to image plane.

[3] See Airworthiness Group Chairman's Factual Report

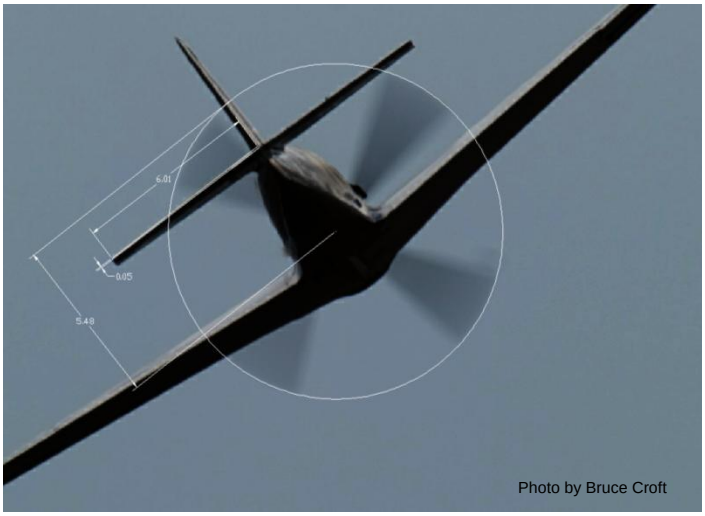


Figure 12. Dimensioned photograph of trim tab deflection (dimensions in feet).

Using the equation in Figure 6 and the known prop diameter of 11 feet 2 inches the pitch angle relative to the camera is 10.0° nose down. After adjusting for the horizontal stabilizer incidence angle, the plane of the trim tab displacement was at a 9° incline to the image plane. Also using the general form of the equation from Figure 11, the trailing edge tab displacement can be found, 0.6 inches. Along with the chord of the tab, 4.32 inches, the tab deflection angle in this photograph is approximately 8° trailing edge up.

A second measurement was taken by directly measuring the trim tab deflection in Figure 13 and correcting for roll angle of the aircraft relative to the camera. The image in Figures 13-14 was captured as the aircraft rounded pylon 2 on the accident flight. It was scaled using the known length of the aircraft. The perceived length in the Figure 13 does not need correction as the yaw angle of the aircraft with respect to the camera is small.

The roll angle with respect to the camera was determined using the known and perceived length of the horizontal stabilizer and rudder hinge using an equation similar to Figure 11 and was found to be 48° left wing down. The perceived elevator deflection, δ_e, and trim tab deflection, δ_t, in Figure 14 were measured and corrected for the roll angle and found to be 2° and 6° trailing edge up respectively.

Both tab and elevator measurement is very sensitive to where the chord line of the horizontal stabilizer, trim tab, and elevator are placed which limits the precision to ±2° on trim tab angle and ±1° on the elevator angle.

Figure 13. Cropped photo of aircraft.

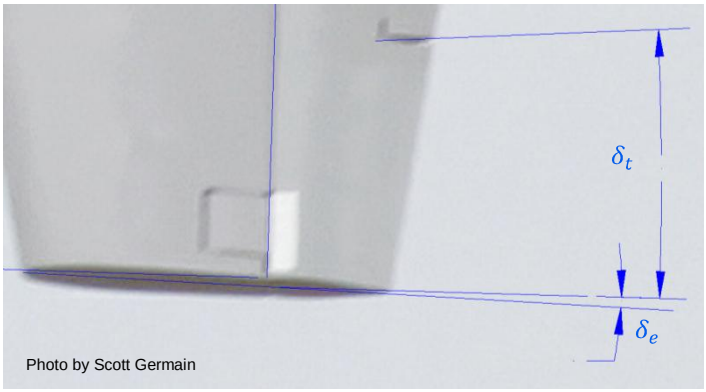


Figure 14. Perceived tab and elevator deflection.

3.3. Documentation of Pilot's Flying Posture

Figure 15, captured as the aircraft rounded pylon 2 on the last lap of the accident flight, shows the pilot's normal flying posture. He is seated leaning forward, away from the seat back. The dual shoulder restraints appear to have no slack in this posture. Figure 16, captured during the 2010 race, appears to show the pilot in a similar posture.

Figure 15. Pilot's normal flying posture.

Figure 16. Pilot's normal flying posture in 2010.

3.4. Fuselage Structural Deformation

Photographs from various times of the accident flight were examined to determine the extent of fuselage deformation was present. Figure 17 shows a cropped image of the right side of the aircraft in the Valley of Speed during the second lap. "Oil canning," or structural deformation in thin walled structure, can be seen on the right side of the empennage. This deformation is not present on the ground. Figure 18 shows similar deformation on the left side of the aircraft as it rounds pylon 2 on the final lap.

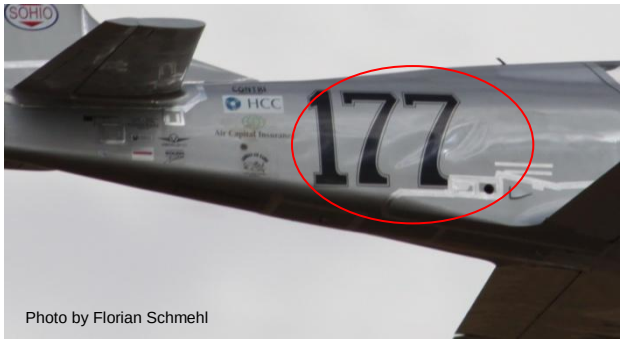


Figure 17. Oil canning on right side during accident flight.

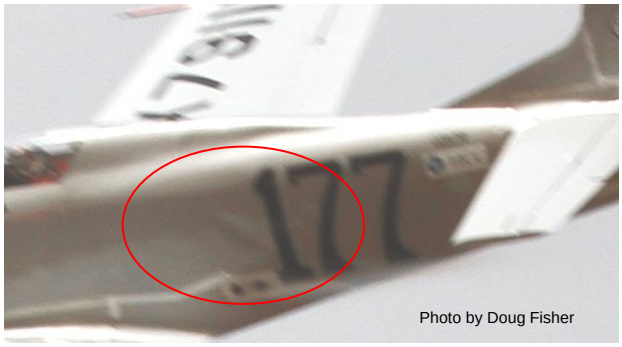


Figure 18. Oil canning on left side during accident flight.

Additionally, Figure 19 shows deformation along the canopy rail and canopy on the first lap of the accident flight in the Valley of Speed. The canopy is not flush with the fuselage as it is in Figure 20 when the aircraft is on the ground.

Figure 19. Canopy out of alignment with fuselage in flight.

Figure 20. Canopy flush with fuselage on ground.

3.5. Documentation of the loss of control sequence

The accident sequence occurred as the Galloping Ghost turned around pylon 8 (Figure 24) when, after an initial yaw/roll upset, it entered a rolling climb maneuver and flew a helical flight path as it descended and impacted the ramp in the spectator area. A series of high resolution images was captured during the loss of control and indicating the position of control surfaces and elevator trim tabs. Figures 24-38 show the series of images of the loss of control sequence.[4] Full resolution copies of all images used in this study can be found the public docket for this accident.

Figure 23 shows the aircraft rounding pylon 8. The positions of the elevator trim tabs are consistent with the observed position during previous laps. Figure 24 shows the aircraft continuing its turn just prior to the roll upset. According to the Video Study, at approximately 16:24:28.8, the aircraft experienced a roll upset to the left. The Airplane Performance Study showed that the roll moment leading to the left roll upset appeared at approximately 16:24:28.2. Figure 25, just prior to the visible roll, shows the aircraft with an increasing right wing down aileron deflection. Figure 26 shows the aircraft approximately 0.5 seconds after the roll upset began. Figure 27 shows the left trim tab trailing edge up

[4] Images not showing background features have been cropped for clarity

and the top of the control rod is seen extending to the edge of or beyond the structure of the airplane (see Figure 21 for zoomed version).

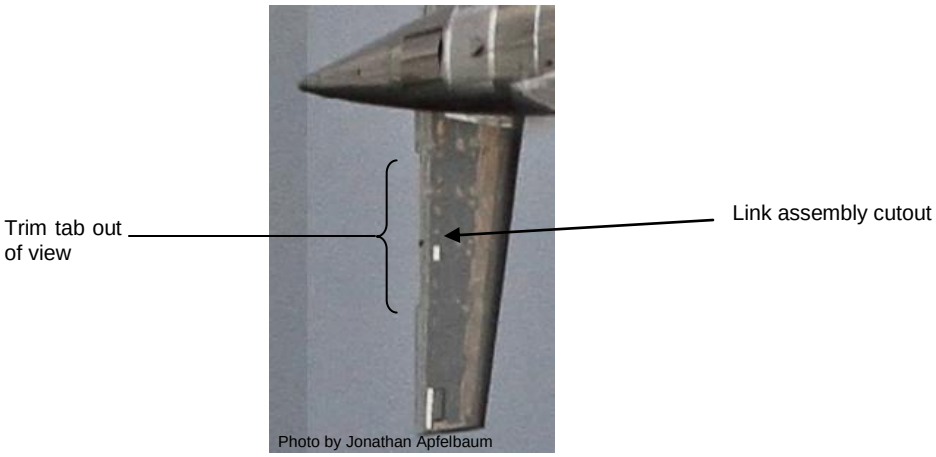


Figure 21. Trim tab not visible.

No part of the trim tab is visible to the camera. The trim tab must be deflected upward at some minimum angle to be out of camera view, obscured by the elevator. According to the video study, the aircraft is banked nearly 88° left wing down at this time, presenting a near flat lateral view of the aircraft to the camera. This allows the wing span of the aircraft, 346 inches, to be used as a true distance against which to scale the photograph. The angle between the longitudinal axis of the aircraft and the image plane, Φ, can be calculated by comparing the known length of a portion of the fuselage, in this case the distance between the spinner and the tail wheel door (343 inches), to its scaled length as measured in the photo. The deflection of the tab with respect to the elevator necessary to obscure the tab from view was calculated according to the Figure 22.

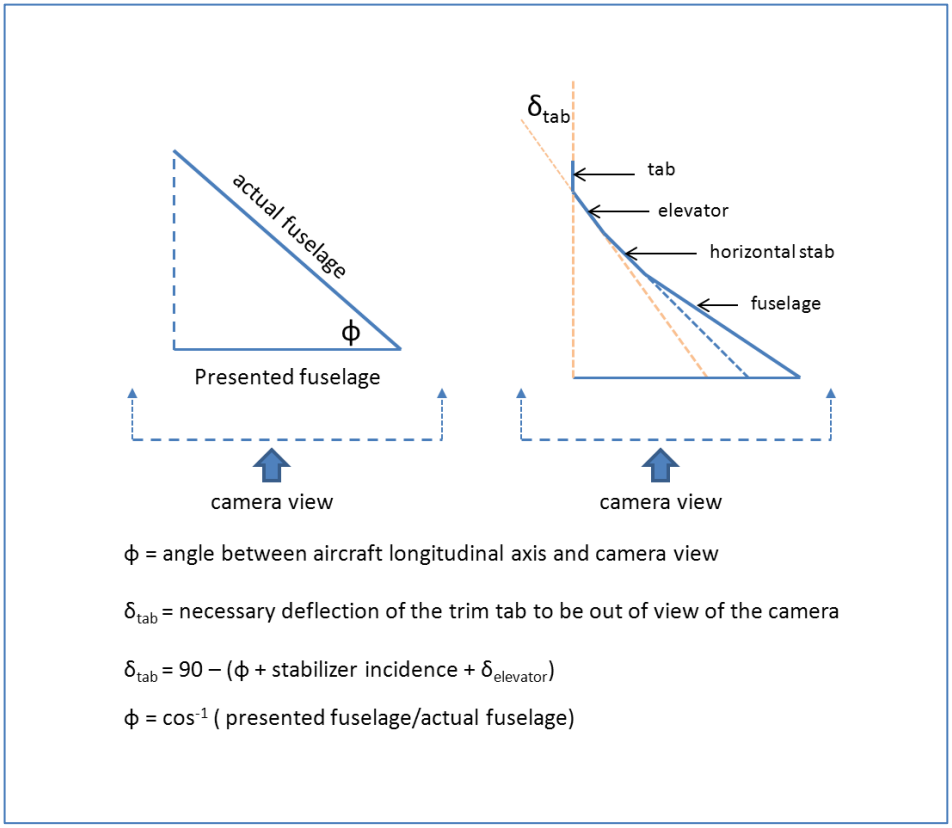


Figure 22. Schematic of trim tab obscuration.

The angle, *Φ*, between the fuselage and image plane was 65°. With the horizontal stabilizer incidence angle of approximately 1° and zero elevator deflection, the tab must be deflected a minimum or 25° trailing edge up to be out of view of the camera. Table 1 shows the minimum tab deflection for a range of possible elevator angles.

Table 1. Minimum tab deflection for range of elevator deflection.

Angle to camera	Stabilizer incidence	Elevator deflection (TEU)	Minimum tab deflection (TEU)
65°	1°	0.5°	24°
		1°	24°
		2°	23°
		3°	22°
		4°	21°

The trim tab system was designed to have at most 13° of trailing edge up travel.[5] A tab deflection greater than 13° indicates that the control rod is broken. The 25° calculation allows up to 12° of uncertainty to the angle of the aircraft, the elevator, and stabilizer. This puts the failure of the left tab link assembly as late as 16:24:29.46 PDT in the accident sequence.

[5] The original P-51D documentation limited the elevator trim tabs to 10° trailing edge up, however measurements made on similar airplanes indicate that 13° of travel is possible.

According to the Video Study, the aircraft reached a maximum bank angle of approximately 93 degrees left wing down, approximately 0.13 seconds after the image in Figure 28 was captured.[6]

Figures 29-32, taken from a different camera, were all taken between 16:24:29.60 PDT and 16:24:30.20 PDT, although the exact time cannot be determined as the Exif timestamp precision was only to the nearest second. The camera used to capture these images, the Canon EOS 1D Mark II, is capable of shooting in two continuous burst modes: a lower speed burst mode with a maximum capture rate of 3 images per second, and a higher speed mode with a maximum capture rate of 8.5 images per second. Four images were captured in 0.60 seconds between 16:24:29.60 and 16:24:30.20. At the maximum image capture rate these images can be no closer than 0.12 seconds apart from one image to the next. Time between image capture can be affected by the selected image compression, speed of image storage medium, and state of the camera's internal memory buffer, so the longer the continuous burst mode is used, the further apart subsequent images will be captured. Figures 29-31 show the aircraft as it rolled to the right after the initial upset. Figure 31 and Figure 32 show the left trim tab deflected trailing edge up and faired with the elevator, respectively.

In Figure 33, the aircraft has rolled to the right and beginning to pitch up. The right elevator trim tab is now trailing edge down and the left tab appears to be faired with the elevator. The tailwheel begins to extend from its housing. In Figure 34, captured 0.14 seconds after Figure 33, the right elevator trim tab is now trailing edge up and the left tab is trailing edge down. Nearly full right wing down aileron is also observed. Figure 35 shows the pilot leaning forward as the aircraft was near the apex of the climb. As the aircraft reached the apex of the climb the left elevator trim tab is visibly detached from its inboard hinge at 16:24:33 PDT (Figure 36). Approximately 1.5 seconds later it separated from the airplane (Figure 37). At 16:24:38 PDT the aircraft impacted the spectator viewing area.

Table 2 summarizes the accident sequence from the collected video and photographic evidence from both the Video Study Report and this Image Study Report.

Table 2. Summary of accident sequence from video and photographs.

Local time (PDT)	Event
~16:24:28.2[a]	Aircraft experiences left roll moment.
16:24:28.9[b]	Aircraft roll left through 73°.
16:24:29.17	Aircraft rounds pylon 8. Left elevator trim tab is trailing edge up, right elevator trim tab is faired with elevator. Increased right wing down aileron deflection observed.
16:24:29.73[b]	Aircraft reaches maximum roll of -93°.
16:24:30.20	Aircraft reaches maximum vertical acceleration, tail wheel begins to extend. Right elevator trim tab is trailing edge down, left tab appears faired with elevator.

[6] See Video Study

Local time (PDT)	Event
16:24:30.34	Right elevator trim tab is trailing edge up, left elevator trim tab is trailing edge down. Ailerons are at or near full right with down deflection.
~16:24:32	Left elevator trim tab detaches at inboard attach point.
16:24:33.5	Left elevator trim tab separates from aircraft.
16:24:38.0[b]	Aircraft impacts spectator viewing area.

[a] from Aircraft Performance Study Report

[b] from Video Study Report

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Figure 23. Aircraft rounding pylon 8 on final lap.

Exif Time	17:23:24.39
Local Time	16:24:28.65 PDT
Resolution	3456x5184
Shutter Speed	1/500

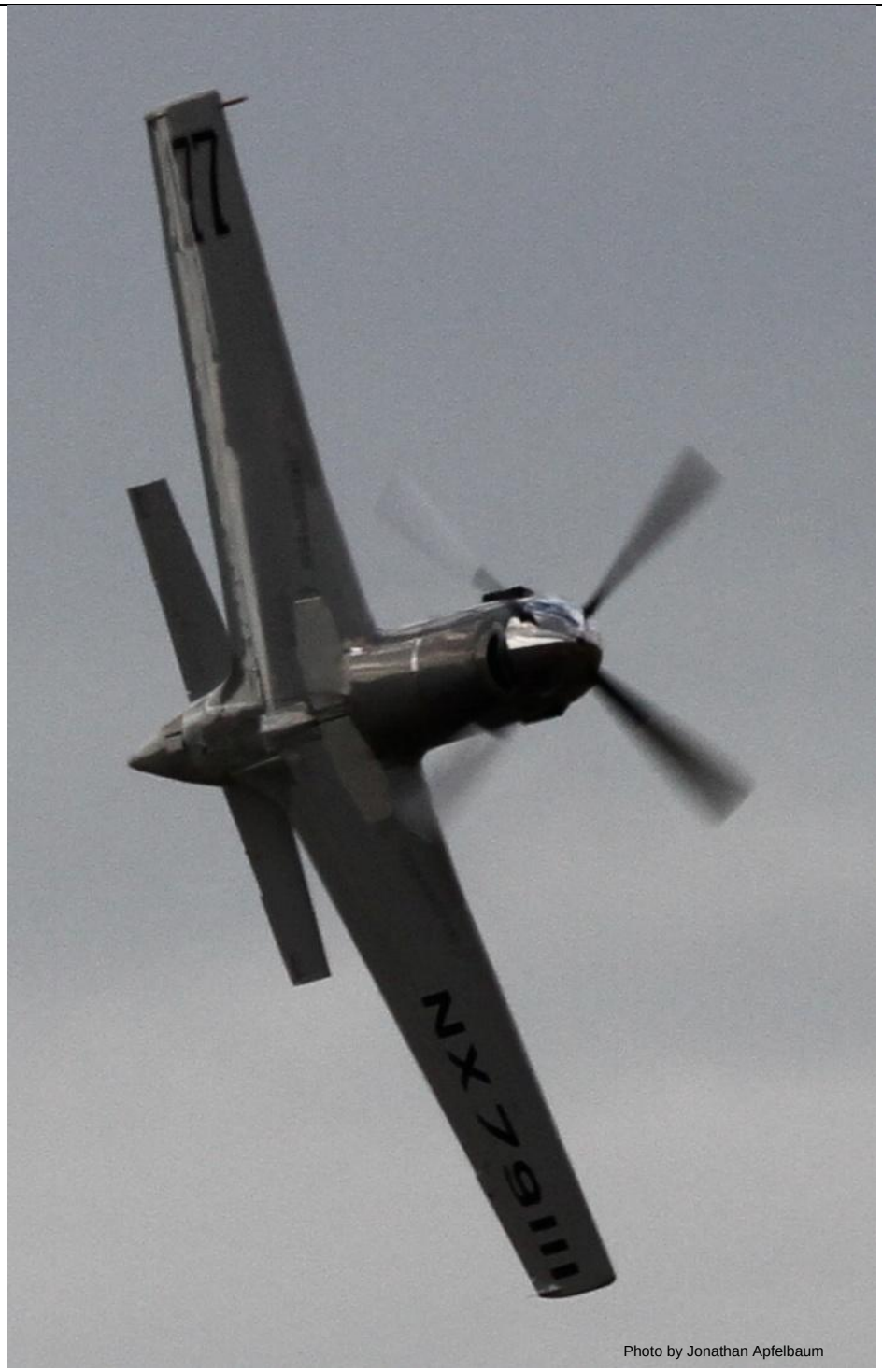

Figure 24. Aircraft just after roll upset begins.

Exif Time	17:23:24.78
Local Time	16:24:29.04 PDT
Resolution	3456x5184
Shutter Speed	1/640

Figure 25. Aircraft in roll upset.

Exif Time	17:23:24.91
Local Time	16:24:29.17 PDT
Resolution	3456x5184
Shutter Speed	1/500

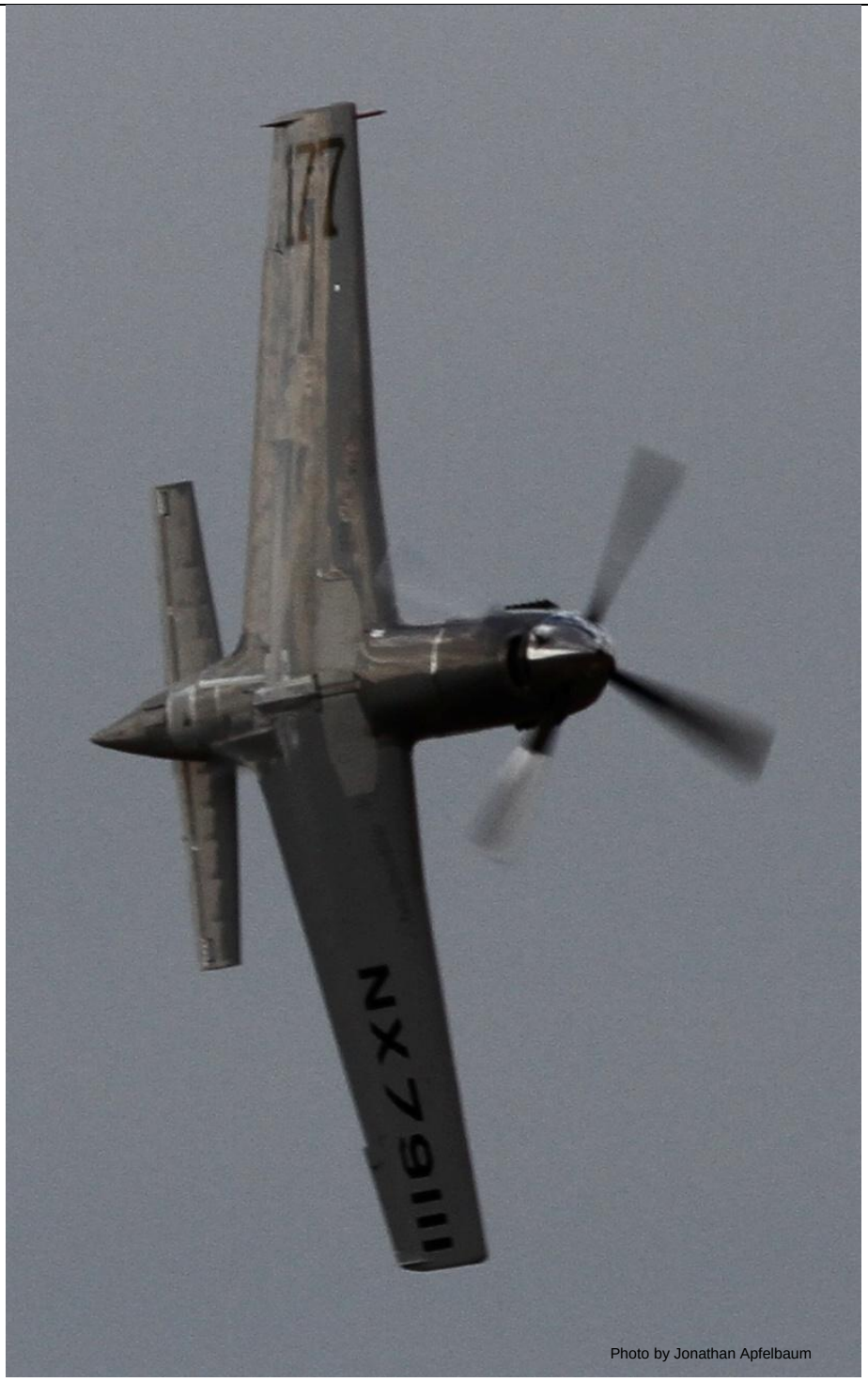

Figure 26. Aircraft in roll upset.

Exif Time	17:23:25.05
Local Time	16:24:29.31 PDT
Resolution	3456x5184
Shutter Speed	1/500

Figure 27. Aircraft in roll upset.

Exif Time	17:23:25.20
Local Time	16:24:29.46 PDT
Resolution	3456x5184
Shutter Speed	1/500

Figure 28. Aircraft just prior to maximum left roll of 93°.

Exif Time	17:23:25.34
Local Time	16:24:29.60 PDT
Resolution	3456x5184
Shutter Speed	1/640

Figure 29. Aircraft recovering from roll upset.

Exif Time	16:24:41
Local Time	16:24:29.60-16:24:30.20 PDT
Resolution	2336x3504
Shutter Speed	1/400

Figure 30. Aircraft recovering from roll upset.

Exif Time	16:24:41
Local Time	16:24:29.60-16:24:30.20 PDT
Resolution	2336x3504
Shutter Speed	1/400

Figure 31. Aircraft recovering from roll upset.

Exif Time	16:24:41
Local Time	16:24:29.60-16:24:30.20 PDT
Resolution	2336x3504
Shutter Speed	1/400

Figure 32. Aircraft recovering from roll upset.

Exif Time	16:24:41
Local Time	16:24:29.60-16:24:30.20 PDT
Resolution	2336x3504
Shutter Speed	1/400

Figure 33. Aircraft at point of maximum vertical load factor.

Exif Time	17:23:25.94
Local Time	16:24:30.20 PDT
Resolution	3456x5184
Shutter Speed	1/640

Figure 34. Aircraft pitching up with near full right wing down aileron deflection.

Exif Time	17:23:26.08
Local Time	16:24:30.34 PDT
Resolution	3456x5184
Shutter Speed	1/640

Figure 35. Aircraft near apex of helical maneuver, pilot slumped forward and to the right.

Exif Time	16:24:39.6
Local Time	16:24:32.3 PDT
Resolution	3264x4928
Shutter Speed	1/640

Figure 36. Left elevator Trim tab detaches at inboard attach point.

Time	16:24:45
Local Time	~16:24:33 PDT
Resolution	3054x2336
Shutter Speed	1/400

Figure 37. Trim tab separates from aircraft 5.3 seconds after left roll upset.

Exif Time	16:24:40.8
Local Time	16:24:33.5 PDT
Resolution	3264x4928
Shutter Speed	1/640