NATIONAL TRANSPORTATION SAFETY BOARD

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AIRWORTHINESS

Group Chairman's Factual Report

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Addendum 3
(19 pages)

A. PURPOSE

The purpose of this Addendum is to summarize factual information from all the different reports and studies written for the investigation in one document. In many cases scientific and engineering principles are introduced to explain effects and provide clarification.

B. DETAILS OF THE ADDENDUM

The accident airplane had a long racing history although some of the information may be in error. Most sources claim that this particular airplane was the original “Galloping Ghost”, NX79111, that participated in the Cleveland Air Races from 1946 to 1949. The airplane has been participating on and off at the National Championship Air Races (NCAR) in Reno since 1969 with varying amounts of success under several different owners. Its racing history includes 2 Unlimited Gold championships as “Jeannie” in 1980 and 1981. James Leeward acquired the airplane and began racing it at the NCAR in 1983. The airplane has been involved in at least three accidents or incidents associated with its modern racing career. Engine troubles required a forced wheels-up landing in Reno during the NCAR in 1970 and again in Van Nuys, California, prior to the 1980 NCAR. During a race sometime between 1983 and 1989, while flown by Mr. Leeward, the canopy and turtle deck separated from the airplane and struck the vertical stabilizer causing significant damage during a race at the NCAR. The exact year of the event could not be conclusively determined.

The airplane was placed in storage for unknown reasons after the 1989 NCAR and did not race again until 2010 after undergoing an extensive overhaul that began in 2007. By all accounts, the intention was to have the airplane ready to participate in the 2009 NCAR but the assembly of the airplane was not completed in time. The overhaul, modification, and assembly work was performed by numerous people and in multiple locations from 2007 to 2009.

1.0 Modifications

The accident airplane had numerous modifications performed over its racing career in an effort to make it faster and to modify its handling qualities. Through examination of the wreckage, interviews of the crew members, and examination of extensive photographic evidence taken during the assembly of the airplane, the group was able to establish the modifications performed with respect to a stock P-51D airplane. In this section an attempt will be made to look at each of the modifications and their effect on the overall performance of the airplane.

The wings on the accident airplane were clipped at the stock production break early in its racing career (July 1970), resulting in a wing span of about 31.5 feet. They were further shortened in 1983 immediately before Mr. Leeward purchased the airplane. At the time of the accident, the wingspan was reduced about 8 feet from the stock wingspan and the ailerons were shortened by more than half to about 3 feet. The right aileron trim tab was removed and the aileron skins were installed to cover the stock trim tab cut out. The manual control wheel for the roll trim was replaced by a toggle switch that actuated an electric actuator to drive the left trim tab. The toggle switch was installed on the left side of the cockpit near where the original trim wheel was installed and the electric actuator was installed on the aft side of the wing rear spar near the centerline. New wing tip caps and end plates were added to the wing tips. The shortened wings would decrease the aspect ratio and allow the airplane to fly faster, would allow the wings to withstand higher flight loads (higher Gs), would increase the wing loading, would increase the stalling speed, would decrease the parasite drag but increase the induced drag, would allow for a faster roll rate due to the decreased aerodynamic roll damping, and would decrease the gross weight of the airplane. The smaller ailerons would decrease the available roll rate at any given deflection and require more aileron deflection to achieve any given roll rate. The net effect of the modifications on the roll rate would be a decrease in the roll rate. The change in the aileron mass, stiffness, and attachment to the wing would have an effect on the flutter characteristics of the ailerons. The right aileron trim tab was removed but is only ground adjustable on the stock airplane. All of the roll trim on the accident airplane was input through the left aileron trim tab. The photographic evidence showed little to no roll trim input in any of the photos. However, the airplane always had a small amount of left aileron trailing edge down while the right aileron was faired with the wing trailing edge. This is evidence that the ailerons were not rigged properly and resulted in some roll trim being accomplished through aileron deflection. The slow speed performance of the airplane would be affected by the wing modifications but should not be much of a concern for a racing airplane. The other highly modified P-51 airplanes in competition at the NCAR only have clipped the wings to the production break (31.5 feet wingspan). Stiletto was the only other airplane known to have wings clipped as short as the Ghost.

The horizontal stabilizer and elevator span was decreased by removing the tip caps and installing a flat close out plate such that the span was about 1 foot shorter that a stock airplane. This would decrease the aspect ratio of the horizontal stabilizer, and have the same basic loading and drag effects as the shortening of the wings discussed above although to a lesser degree since the percentage change was much less. This modification is typical of almost all of the racing Mustangs and was performed on the airplane prior to Leeward owning it.

The elevators and trim tabs were of all metal construction but had up to 1/8 inch of filler material on the upper and lower skins. Lightweight filler was used to smooth the contour of the surfaces presumably in an attempt to lessen the parasite drag on the surfaces. The added weight of the filler material aft of the hinge line on the elevators would change the balance characteristics and necessitate a small increase in the weight of the elevator counterweight. The addition of filler to the elevator trim tabs would increase the weight of the tab and move the CG aft causing an increase in the flutter susceptibility of the control surface and an increase in the wear on the hinges.

The group examined a set of stock all metal trim tabs from Precious Metal that were similar in construction to the Ghost tabs except they were bare metal with no filler material to determine the weight and CG position. The bare tabs weighed about 667 grams and 686 grams and both had a CG location about 2.725 inches forward of the trailing edge. The group also examined a set of all metal trim tabs from Voodoo that were similar in construction to the Ghost that utilized flush head rivets (as opposed to the button head rivets used on the Ghost tabs) and that had filler material applied. The tab control horn, however, was of a different design than the Ghost. The filled Voodoo tabs weighed about 887 grams and 894 grams and both had a CG location about 2.56 inches forward of the trailing edge.

The left and right elevator counterweights were recovered in the wreckage and each weighed about twice their normal weight (26 lbs. rather than the original 13.75 lbs.). While a small portion of this increase should be expected due to the increased elevator weight caused by the addition of filler, it was evident based on the build photos that these elevators were significantly over-balanced. The CG of the Ghost elevators was forward of the elevator hinge line which will affect the control stick forces and the flutter characteristics of the elevators. Typically, reversible flight controls such as the elevators are statically balanced at the hinge line (or nearly so) to provide the necessary control forces and hinge moments. The overbalanced elevators would lessen the stick forces required to maneuver. For example, the nose up control stick force required at higher flight loads would decrease making the airplane more sensitive in pitch.

The stock airplane originally had a horizontal stabilizer incidence of 2° leading edge up that was subsequently reduced to ½° nose up per the instructions in TO 01-60-100. The accident airplane had the forward attach brackets that correspond to ½° of incidence installed based on the scaled and annotated photograph in Figure 9 of the factual report. In addition there were 0.135 inch thick shims installed between the forward horizontal stabilizer attach points and the empennage. Per drawing 73-21001 the distance between the forward and aft attach points is 18.937 inches. The amount of increased incidence from the 0.135 inch shims can be calculated using:

$$\theta = \tan^{-1}\frac{0.135}{18.937}$$

$$\theta = 0.41°$$

Including the stock brackets and the installed shim, the airplane had a horizontal stabilizer incidence of 0.91° leading edge up. One of the crew members indicated that this incidence was the same as when Mr. Leeward purchased the airplane. Since the P-51D utilizes a symmetrical airfoil for the horizontal stabilizer and elevator any increasing amount of leading edge up incidence will result in less down force (or more up force) on the horizontal stabilizer due to an increase in the local angle of attack of the airfoil at any particular speed. In general, for a conventional airplane, as speed increases, the amount of down force produced on the tail increases causing the airplane to tend to pitch nose up and requiring more downward elevator deflection (forward stick) to maintain level flight. Increasing the nose down trim setting will deflect the elevator trim tab trailing edge up and relieve the forward stick forces required to maintain level flight. For the racing Mustang a higher horizontal stabilizer incidence is more beneficial at the high race speeds typically flown.

The pitch trim control system on the airplane was modified by changing the elevator trim tab set up, adding an electric trim actuator, and reducing the elevator inertia weight (commonly referred to as a bob weight). The right elevator trim tab was fixed in place by installing a steel rod between the trim guide and the trim tab link assembly. The steel rod was supported at the horizontal stabilizer rear spar and the forward support was eliminated with the elimination of the trim tab actuator. The eliminated support and cantilevered arrangement of the rod off the rear spar would decrease the system stiffness. The left elevator trim actuator was stock and controlled through the electric actuator attached to the horizontal stabilizer front spar. The trim was actuated by a toggle switch installed in the trim panel near where the trim wheel would have been installed on a stock airplane. The crew reported that the trim would travel from full up to full down in about 20 seconds, which works out to a 1.75° per second trim rate. A trim runaway would have developed slowly due to the relatively slow rate commanded by the actuator. The cables and right trim actuator were removed from the airplane. The design of the trim actuator allows the left trim tab to creep trailing edge up and the right to creep trailing edge down if there is no restraining cable force on the trim drum and if a vibratory load is placed on the tabs. With the deletion of the right actuator and cables the restraining force from the cables was eliminated. The S-TEC trim actuator installed for the left elevator trim tab would freewheel when power was not applied so there would be no restraining cable tension on the left trim actuator as installed on the accident airplane. To re-trim the airplane the pilot would have to remove his hand from the throttle in order to actuate the trim switch. The single left trim tab also required an increase in the aerodynamic load on that trim tab for a given flight condition as compared to the stock system. The redundancy of the pitch trim system was removed by actuating only one trim tab.

The crew all believed that there was no pitch trim required at race speed due to the way the airplane was set up. There was a zero trim indicator light in the cockpit that would be illuminated when the trim was at zero. The photographic evidence presented showed that a significant amount of nose down trim (5° to 8° trailing edge up) was input on the left trim tab during the accident race and other flights on the course. The actuation of only one trim tab would produce an unbalanced force on the horizontal stabilizer that would tend to twist the empennage with respect to the wing. The empennage would tend to twist to the right (as viewed from the tail looking forward) with respect to the wings given the nose down trim photographed on the left elevator trim tab during the race. In addition, different tab deflections introduce different hinge moments into each elevator and additional stresses in the elevator torque tube. Photos show a small elevator split while the airplane was at race speeds that was not present while the airplane was on the ground.

The elevator inertia weight (bobweight) was installed on the forward elevator bellcrank during service in order to increase the stick forces during maneuvers. The weight was not identified in the wreckage but the deformation of the installation holes on the bellcrank indicates that it was installed. Further, the crew verified that it was installed. Based on photos the group determined that the bobweight was smaller than the original stock bobweight. Utilizing the drawing in conjunction with the photos, the amount of material removed was estimated and the weight calculated. There is no evidence of the P/N 109-52217-4 support tube in the photo of the bobweight and it appears that the weight is cut at the brackets. It was assumed that 2.5 inches was cut from each ear of the bobweight so that the total weight cut off is given by:

$$W = \ \frac{1}{2}\ b_1 + b_2\ h - \frac{1}{2}bh\ \ l\rho$$

$$= \ \frac{1}{2}\ \ 2\frac{15}{16} + 3\frac{1}{16}\ \ 2\ -\frac{1}{2}\ \frac{1}{2}\ \ \frac{15}{32}\ \ 5\ \ .410$$

$$= 12.06\ lbs$$

W = Weight (lbs)
b=base (in)
h=height (in)

l=length (5 in)
ρ=density of lead (.410 lb/in^3)

The stock bobweight should weigh 20.75 pounds according to the drawing. The Ghost bobweight weighed about 8.69 pounds in its installed configuration. The lighter bobweight would reduce the stick forces required during maneuvers and make the airplane more sensitive in pitch. This would be additive to the decrease in stick forces caused by the increased elevator counterweights.

The rudder was a stock fabric covered structure that was painted. The rudder trim tab was eliminated from the rudder and covered over with fabric. The upper rudder counterweight was increased about 8 pounds. Many of the racing Mustangs have removed the rudder trim tab based on the pilot preferences but no similar airplane could be found with an overbalanced rudder. The over balanced rudder would change the CG, the flutter characteristics of the control surface, and the response to lateral dynamic perturbations. The stock airplane has a vertical stabilizer incidence of 1° leading edge left. A tapered shim similar in dimension to the stock shim but oriented opposite was installed on the vertical stabilizer rear spar and the front spar attach bracket was modified such that the Ghost had a vertical stabilizer incidence set leading edge right. The group was not able to determine the exact amount but it appeared to be about 1°. The right incidence of the Ghost vertical stabilizer would tend to yaw the airplane to the left and may make it easier to fly on a left turn course such as at the NCAR. However, the left yaw would require more right roll input.

Two of the most noticeable modifications to the fuselage involved the installation of a racing canopy and turtle deck and the elimination of the distinctive lower air scoop from beneath the wing. The racing canopy was smaller than the original with less frontal area that would result in less drag on the airplane. The structure above the upper longeron was replaced with modified structure designed to fair in the canopy and give an aerodynamic shape to the aft upper fuselage. According to the crew, portions of this structure came from a previous racer. There were no drawings or technical information available for the modified structure. It is possible that the turtle deck structure was not as strong or stiff as the original structure which would cause a decrease in the stiffness or rigidity of the aft fuselage. The lower air scoop was removed from the lower longerons beneath and behind the wing and replaced with a piece of structure that was previously installed on the racer Stiletto. The structure was designed to fair the wing and fuselage and provide an aerodynamic shape to the lower fuselage. There were no drawings or technical information available for this structure. It is also possible that the lower fairing was not as strong or stiff as the original structure which would cause a decrease in the stiffness or rigidity of the aft fuselage. The deletion of the scoop also would have an effect on the aerodynamics of the airplane from the center of the wing back that would change the airflow around the aft half of the airplane. The stiffness or rigidity of the aft fuselage was changed due to the installation of the racing canopy and the deletion of the lower air scoop with respect to a stock P-51D.

The engine coolant and engine oil radiators normally installed in the air scoop were relocated to their own tanks installed aft of the pilot seat. The tanks bathed the radiators in a water/methanol mixture that would boil off and provide cooling. The boilers were situated on a stiffened floor that was installed between the upper and lower longerons aft of the cockpit. The floor measured 0.104 inch thick. There was no technical data or a loads analysis provided for the structure.

The airplane had a modified race engine installed and the stock elastic engine mounts were replaced with solid engine mounts. The propeller installed was an unmodified Hamilton Standard cuffed prop. The stock aluminum inlet duct was replaced with a carbon fiber duct. These modifications are somewhat standard on race Mustangs. The stock elastic engine mounts were intended to provide for a secure installation while isolating the airframe from engine vibrations. The solid aluminum engine mounts would eliminate any changes in engine geometry that occur due to the high race-power settings but would allow more engine vibration to be transmitted into the airplane structure.

The stock airplane seat was installed along with a 5 point safety harness to secure the pilot. The shoulder harnesses could be manually locked in any position. Photographic evidence showed that the pilot utilized the safety harness during the race but the use of the locking mechanism could not be determined. The portable oxygen bottle valve was found in the wreckage and sent for x-ray examination. The end of the threaded section attached to the handle was not seated against the bottom of the opening which indicates that the oxygen bottle valve was open at the time of impact. The crew reported that the oxygen in the bottle would last for several races. It was not determined when the bottle was last filled.

No drawings, documentation, or analysis of the modifications were provided to the investigation and there was no indication that any existed.

2.0 Wreckage Examination

The airplane was extremely fragmented due to the impact forces. The largest piece of wreckage was the remains of the empennage that included the vertical stabilizer, the inboard portion of the right horizontal stabilizer, the elevator control horn, the rudder control horn, the inboard portion of the left elevator, the inboard portion of the left horizontal stabilizer, the aft fuselage, and portions of the tail wheel retract mechanism. All of the control cables examined in the wreckage exhibited a splayed appearance consistent with tension overload failure. This combined with the photographic evidence indicates that there was no evidence of flight control issues up until the time of the roll upset.

An additional piece of structure was installed on the aft spar of the left horizontal stabilizer where the trim tab actuator rod passes through the trim guide. The crew chief confirmed that the structure was installed to provide additional support to the rod at the aft edge of the horizontal stabilizer, aft of the existing trim guide on the rear spar. Examination of Voodoo revealed an additional trim guide installed at the aft edge of the horizontal stabilizer similar to that required by an Australian Technical Order. The grease fitting was not installed in the left trim guide on the Ghost and there was no evidence of fresh grease in the fractured guide. Examination of the photos showed that the additional support structure was not installed as part of the build-up of the airplane and the crew chief confirmed it was installed later. There was no additional support structure installed in the right horizontal stabilizer.

The identified portions of fuselage skin were all measured to determine the thickness. The fuselage skin thicknesses measured were all consistent with the stock required thicknesses.

3.0 Airworthiness, Registration, and Maintenance

Mr. Leeward purchased the airplane in 1983 and Bahia Oaks, Inc. and Aero-Trans Corporation (both d/b/a Leeward Aeronautical Sales) have been the registered owners ever since. Both corporations have Mr. Leeward as president. About a month after purchasing the airplane (on August 17, 1983) a Special Airworthiness Certificate in the Experimental Category was issued for the purposes of Exhibition and Air Racing, and Operating Limitations with the same date were issued as part of the certificate. The airworthiness certificate was re-issued in 2010 to replace a lost certificate but the same operating limitations remained in effect.

The following limitations will be discussed in more detail. All other Operating Limitations were complied with.

2. Proficiency flights must be conducted within a 100-mile radius of Leeward Air Ranch Airport, Ocala, Florida. Aircraft is to be based and maintained at Leeward Air Ranch Airport, Ocala, Florida. Proficiency flights may be conducted enroute to air shows and racing locations.

9. The cognizant FAA Flight Standards Office must be notified and their response received in writing, prior to flying this aircraft after incorporating a major change as defined by FAR 21.93.

11. This aircraft shall not be flown unless it is maintained and operated in accordance with technical order AN-01-60JE-2, -3, -4, -5, & -6.

The airframe logbook was examined and found to contain very few entries. Particular attention was paid to those entries since 1983 when the airplane was purchased by Mr. Leeward and those since the airplane was transformed to the Ghost in 2009. There was an error in the aircraft total time entered as part of the assembly and condition inspection entry dated September 16, 2009. The total time of 1422.5 hours was brought forward from the September 7, 1988, condition inspection entry instead of the total time of 1428.9 hours from the August 30, 1989, condition inspection entry. The total times from September 16, 2009, on should be increased by 6.4 hours. At the last condition inspection performed on July 19, 2011, the airframe total time should have been 1453.6 hours. Between the assembly of the airplane in fall 2009 and the July 2011 inspection the airplane had accrued a total of 24.7 hours, 14.2 hours of these were accrued prior to the 2010 races. The airframe, engine, and propeller had condition inspections performed and documented in accordance with Operating Limitations 13, 14, and 15. The 2009 inspection was signed off as an 'aircraft' inspection and thus applied to the engine and propeller. The 2011 inspection was signed off as an 'airframe' inspection and there were corresponding inspections for the engine and propeller.

The airplane had not been based in Ocala, Florida, since it began the transformation to the Ghost at GossHawk Unlimited in Arizona in April 2007. The airplane was moved from Arizona to Texas and finally to Minden, Nevada, in fall 2009. After assembly the airplane remained based in Minden, Nevada, and all of the flights were conducted in the vicinity of the Minden airport or at the NCAR.

In 2009 Mr. Leeward began communicating with the FAA-Reno FSDO, by phone and email about the Ghost and its modifications. The FAA was informed that the airplane had a major change, the installation of a boil-off cooling system, and Mr. Leeward was notifying them in accordance with Operating Limitation 9. FAR 1.1 defines major alteration and the operating limitations refer to FAR 21.93 for the definition of minor change, all others then are considered major. The installation of the boil-off cooling system is a major change since it affects the weight, balance, and powerplant operation of the airplane. The FAA responded in writing to concur with the proposed 3 hours, and 3 take-offs and landings, of flight testing required to validate the installation of the boil-off cooling system. They also suggested the entry that should be made in the airframe logbook once the testing was completed. The suggested entry was entered and signed off by Mr. Leeward on September 22, 2009. Based on the photographic evidence and discussions with the crew and other racers the airplane first flew on September 21, 2009. An attempt was made on September 19, 2009, but the airplane never lifted off the runway due to the presence of methanol fumes in the cockpit. Nothing was done on Sunday, September 20, 2009, since the crew took the day off to attend the NCAR and watch the Unlimited Gold race. The recorded data from the airplane telemetry system shows that a total of 5 flights were initiated but 3 of them didn't contain any data. About 23 minutes of flight time data was accrued on September 21 and 22, 2009, by the telemetry system. Assuming that there were 5 flights completed during these two days and that they were each 20 minutes in length, the airplane did not accrue 3 hours of flight time.

Per the operating limitations the airplane was to be based in Ocala, Florida as discussed above and the cognizant FSDO in Florida should have been notified of the major changes to the airplane. However, Mr. Leeward notified the Reno FSDO about the modification since the airplane was actually based in Minden, Nevada.

The deletion of the lower air scoop, over balancing of the elevators and rudder, reduction in the bob weight, fixing of the right elevator trim tab, and the changing of the horizontal and vertical stabilizer incidence would affect the structural strength, performance, and flight characteristics of the airplane and should be considered major changes. The owner should have notified the FAA of the major changes prior to flight.

Per FAR 91.319(b) the accident airplane should have had a flight test program performed in a specific area defined by the FAA to show that it is controllable throughout its normal range of speeds and throughout all the maneuvers to be executed and has no hazardous operating characteristics or design features. The available information indicates that the accident flight was the fastest the airplane had been flown on the course at Reno under the unique load factor regime required to negotiate the course.

Operating Limitation 11 listed several manuals that must be used to maintain and operate the aircraft. No reference could be found for the manual AN 01-60JE-5, however, a reference was found to the AN 01-60J-5 Basic Weight Checklist & Loading Data. Likewise, no reference could be found for the manual AN-01-60JE-5, however, a reference was found to the AN 01-60J-6

North American P-51 1943 Service Letters, Bulletins. The P-51 operators and the type certificate holder that we contacted, with the exception of the Ghost crew chief, were not aware of the -5 and -6 manuals and had never seen copies. The original manuals for the stock airplane have limited applicability to a highly modified airplane such as the Ghost.

4.0 Flights

The airplane was equipped with a data gathering and telemetry system to allow the crew to monitor the airplane during racing in real time. The NTSB obtained the telemetered data from the accident flight and many other flights. All of the data was examined by the NTSB Data Recorder Specialist and selected flights were plotted in the report.

The telemetered engine data for the accident flight was examined to determine the state of the engine during the race. The data gave a good indication of the health of the engine and would have disclosed problems or impending problems with the engine. The oil temperature was about 78°C as the airplane was coming down the chute and climbed steadily to between 84º C and 86º C, as the airplane sped up on the course (and remained steady for the remainder of the flight). The oil temperature was measured at the boiler output so there should be little change if the boiler is operating correctly. The steady temperature values were at the low end of the normal operating range for the oil temperature and showed that the boil-off system was keeping things fairly constant. The oil pressure was about 105 psi as the airplane was coming down the chute to begin the race. About the time that the airplane leveled off on the course the oil pressure dropped to 70 psi within 2 seconds and stayed at this level for the remainder of the race. There was no corresponding change in any of the other engine parameters at the time of the pressure drop to explain the reduction. Oil pressure in the 70 psi range is not sufficient to supply the entire engine with oil and will generally result in overheating and failure of the engine in a short period of time, however, the crew reported that the oil pressure typically was about 10 psi low on the telemetered data. The crew member watching the engine parameters during the race did not recall seeing the drop and was not alarmed by the data that was being displayed on his monitor. Engine oil pressure in the 80 psi range is sufficient for satisfactory engine operation but is on the low side.

Engine RPM and manifold air pressure (MAP) determine the engine power and thus speed for the race. Normal procedure for the P-51 is to set the throttle to the desired setting of manifold pressure then adjust the propeller RPM for the desired value. Once the RPM is set power changes are accomplished by changing the MAP. Typically, the friction lock is tightened down and the RPM should stay essentially constant during the race. During the accident flight, the Ghost had a step approach to the final power setting. As the airplane was coming down the chute the MAP started at 65 in Hg and reached 100-105 in Hg about 30 seconds later (about the time the airplane leveled off on the course). It stayed at this level for about 40 seconds then increased again about 10 in Hg. For the remainder of the race the MAP oscillated between 105 in Hg and 115 in Hg. The oscillation occurred at a relatively long cycle period of about 5-10 seconds. About 8 seconds prior to the upset the MAP decreased to 105 in Hg. There was a lot of variation in the RPM from the time the airplane started down the chute until the upset event. The RPM increased in steps until it reached the final setting of between 3400 RPM and 3500 RPM almost 2 minutes after it started down the chute. There was a noticeable relatively long period (5-10 seconds) oscillation in the RPM that matched the MAP oscillation. The oscillation in the RPM and MAP is unexpected and suggests that the pilot was having trouble keeping a constant power setting for a majority of the race when racing at the highest power settings. The oscillation was not evident in any of the other flights on the course which were all at significantly lower power settings and higher oil pressures. There was a reduction in power about 8 seconds prior to the upset that was evident in both the RPM and MAP. The data for the power reduction appears valid and there was no evidence of the long period oscillation at the reduced settings. After the upset the MAP dropped and the RPM had a significant reduction then increased substantially in a short period of time. The engine was producing power throughout the accident flight.

The accident airplane in its accident configuration began racing at the NCAR in 2010. The airplane was not able to qualify in 2010 since the pilot missed the pre-race briefing. However, the airplane and pilot were allowed to enter as a conditional entry. The investigative group received data from four flights on the NCAR course in 2010. The first flight was conducted on Tuesday, September 14, 2010, prior to the beginning of the races and was an attempted qualification run on the course. No qualification times were posted for this attempt so the airplane became a conditional entry. As a conditional entry the airplane had to start at the bottom of the field and work its way up through the field by winning each race. The airplane raced in and won the medallion race on Thursday, September 16, 2010, raced in and won the bronze race on Friday, September 17, 2010, and raced in and won the silver race on Saturday, September 18, 2010. The Sunday gold race was cancelled due to high winds in 2010. During these races the airplane posted official race speeds of 338.424 mph (294 knots), 365.505 mph (318 knots), and 373.284 mph (325 knots), respectively. The investigation received data from two flights on the NCAR course prior to the start of the races in 2011, both on September 13, 2011. There were two official qualification speeds recorded by RARA of 436.418 mph (379 knots) and 465.807 mph (405 knots). Including the accident flight, the data from 7 runs on the NCAR course was supplied to the investigation and plotted in the data report.

A summary of some of the data is contained in Table 1 below. The 9/14/10 flight on the course was 2 laps and the airplane reached a maximum speed (GPS) of about 425 knots, the vertical load factor ranged from 0 to 4.4 G's, and the altitude (GPS) ranged from about 5200 feet to 7500 feet[1]. During the second lap of the run the airplane made a pull up of about 1500 feet then came back down about 1000 feet to continue on the course. About 8-10 seconds later the airplane again pulled up but did not re-enter the course. Prior to each pull up there was a significant short period oscillation in the airplane load factor of up to 3.5 G and both occurred as the airplane was reaching speeds in excess of 400 knots. According to the crew, Leeward pulled up because he inadvertently turned off the switches controlling the boilers and the engine temperatures began increasing. The crew also reported a suspected landing gear door issue during the flights prior to the 2010 NCAR due to the illumination of a light in the cockpit. Several gear swings were reportedly performed and the rigging of the gear door system was checked. The airplane did not fly on the course at these high speeds for the remainder of the 2010 races.

The 9/16/10 race on the course was 6 laps and the airplane reached a maximum speed of about 380 knots on the last lap, the vertical load factor ranged from about 0 to 3.6 G (only reached up to 3.0 G prior to the last lap), and the altitude ranged from about 5000 feet to 5600 feet. During

[1] All of the speeds and altitudes in this section, unless otherwise noted, refer to the values recorded by the telemetry receiver. The speed, in knots, was calculated by the system and is a GPS ground speed.

the last lap of the race as the airplane reached its maximum speed there was a short period oscillation of the load factor of up to 2.0 G that was markedly different from the rest of the race. The 9/17/10 race was 6 laps and the airplane reached a maximum speed of about 360 knots, the vertical load factor ranged from about 0 to 3.6 G, and the altitude ranged from about 5000 feet to 5800 feet. The 9/18/10 race was 6 laps and the airplane reached a maximum speed of about 410 knots, the vertical load factor ranged from about -0.1 to 4.3 G, and the altitude ranged from about 5000 feet to 5800 feet. The speed and load factor were greatest during the first 1.5-2 laps and then the airplane ran less than 350 knots and less than 3.0 G for the last 3 laps. As the airplane was flying at its fastest speed there was a short period oscillation of the load factor of up to 3.0 G that was different from the succeeding laps.

The first flight on 9/13/11 was about 6 laps and the airplane reached a maximum speed of 420 knots, the vertical load factor ranged from about -0.4 to 4.8 G, and the altitude ranged from about 5200 feet to 6500 feet. The speed and load factor are highest during the last 2 laps of the run where a short period oscillation of load factor can be seen similar to the previous races. The second flight on 9/13/11 was about 5 laps and the airplane reached a maximum speed of about 390 knots, the vertical load factor ranged from about 0.2 to 4.2 G, and the altitude ranged from about 5000 to 6000 feet. The load factor remained below about 3.6 G until the last 2 laps. There was some evidence of the short period oscillation in load factor of up to 3.0 G during the last 2 laps.

The accident flight on 9/16/11 completed less than 3 laps and the airplane reached a maximum speed of about 460 knots, the vertical load factor ranged from about 0 to 4.6 G with a single spike of about 7.0 G, and the altitude ranged from about 5100 feet to 5700 feet. There was some evidence of the short period oscillation in load factor but the GPS based velocity and position data were not valid for much of the flight so a correlation was difficult to make. The 7.0 G spike occurred at about 16:23:21 and corresponded to a location on the course at the end of the ‘valley of speed’ just prior to pylon 7. The telemetry data showed an altitude increase of about 200 feet and occurred after the airplane reached its lowest recorded altitude for the flight. Examination of the video showed a rolling climb maneuver at this point on the course consistent with the data recorded. The data from Voodoo was also examined and compared to the Ghost data. Voodoo recorded several high G spikes during the accident race of about 5.5 G, 4.7 G, and 6.2 G and one of about 4.2 G at the same point on the course where the Ghost recorded 7.0 G. The Voodoo acceleration data appeared smoother than the Ghost data and did not have evidence of the short period oscillation noted in the Ghost data. The maximum load factors during the race were similar between the Ghost and Voodoo.

Date	Laps	Max Speed (knots)	Load Factor (G)	Altitude (feet MSL)
9/14/10	2	425	0.0 – 4.4	5200 – 7500
9/16/10	6	380	0.0 – 3.6	5000 – 5600
9/17/10	6	360	0.0 – 3.6	5000 – 5800
9/18/10	6	410	-0.1 – 4.3	5000 – 5800
9/13/11	6	420	-0.4 – 4.8	5200 – 6500
9/13/11	5	390	0.2 – 4.2	5000 – 6000
9/16/11	2+	460	0.0 – 4.6 (7.0)	5100 – 5700

Table 1 – Summary Ghost Flight Data

Some general observations can be made about the flights on the NCAR course. The pilot tends to fly higher and deviate more in altitude during practice and qualifying runs on the course than during actual races. The accident flight was the fastest that the airplane had flown on the course by about 35 knots. There was a noticeable increase in the maximum load factor and a distinctive short period oscillation in load factor as the airplane neared and exceeded about 400 knots. The short period oscillation in load factor was most pronounced at two places on the course, turn 4 and turn 8 which are both situated at the ends of small straight portions of the course. The load factor oscillations are consistent with a change in pitch instability as the airplane speed is near or above 400 knots. The accident flight had the highest MAP and RPM of any flight that we had data for by about 15-20 in Hg and about 100-150 RPM, respectively.

Portions of 5 flights were also plotted that involved various dive or pull up maneuvers to higher load factors. All of the other flights where data was recorded were also examined but not plotted. The flight on 8/16/10 began at about 310 knots and reached about 3.6 G, the first flight on 9/17/10 began at about 310 knots and reached about 5.3 G, and the second flight on 9/17/10 involved two dives, one that began at about 280 knots and reached about 4.4 G and the other that began at about 290 knots and reached about 2.8 G. The flight on 9/18/10 began at about 330 knots and reached about 3.8 G and the flight on 9/9/11 began at about 310 knots and reached about 2.9 G. None of the flights for which there was data approached the recorded GPS speeds that the airplane attained on the race course. The peak load factor of 5.3 G on these test flight was higher than the load factor on any of the race flights with the exception of the one spike on the accident flight before the upset. There was no evidence of a load factor oscillation on any of the pull up flights.

5.0 Weight and Balance

The airplane was weighed after it was assembled in 2009 and had an operational empty weight of 6,474 pounds at a CG of 135.38 inches. This included the operational weight of the fluid in the boilers but did not include the pilot. The CG limits were given as 135.77 inches to 143.8 inches, the same as the stock airplane as approved by the FAA on the type certificate. Based on data gathered as part of the investigation, interviews with the crew, and assuming some conservative fuel and ADI burn rates, the weight and CG at the time of the upset was determined. The fuel density used was 6 lbs/gal and the ADI density was 7.45 lbs/gal, and the empty weight was 6674 lbs at 136.48 inches. ADI was put in the (right) wing tank and fuel was put in the (left) wing tank. More ADI would be used during a race than fuel so the amount of ADI limited the duration of a flight. The crew would calculate how much ADI was needed to complete the race and then add enough fuel to balance the weight in the wings. It was assumed that 15 gal of ADI would be used during the start, warm-up, and taxi out, 20 gallons of ADI would be used during the take-off and join up, and 20 gallons of ADI would be used for cool-down and recovery. It was then assumed that the maximum power setting of 3500 RPM at 115 inches MAP was used for the duration of the 6 lap race (with lap times of 1 minute, 10 seconds per lap) which yielded an ADI use of 70 gallons for the race. The total ADI used for a race would be 125 gallons that was balanced with 155 gallons of fuel. The starting weight and balance was calculated to be 8,535.25 pounds with a CG located 142.26 inches aft of the datum. Based on the telemetry data for the accident race the following constant engine powers were used to calculate the amount of fuel and ADI burned from the time that power came up on the engine for takeoff until the roll upset at 16:24:28.9 PDT.

16:14:15 to 16:16:50 (2.58 min), RPM 3000, MAP 60 inches
16:16:50 to 16:18:15 (1.42 min), RPM 3000, MAP 40 inches
16:18:15 to 16:20:50 (2.58 min), RPM 2800, MAP 50 inches
16:20:50 to 16:21:55 (1.08 min), RPM 3200, MAP 105 inches
16:21:55 to 16:24:29 (2.57 min), RPM 3500, MAP 115 inches

The weight of fluids used for each time segment can be calculated using:

$$W = t\ \ \rho_{fuel}\mu_{fuel} + \rho_{ADI}\mu_{Engine\ ADI} + \rho_{ADI}\mu_{Boiler\ ADI}$$

W = Weight (pounds)
t = time (min)
ρ = Density (lbs/gal)
μ = Burn Rate (gal/min)

Based on the above assumptions, at the time of the upset the airplane weighed 7,765 pounds with a CG located at 140.2 inches aft of the datum. Assuming race power of 3500 RPM and 115 in Hg MAP the airplane was using about 110 pounds of fuel and ADI per minute. The CG was moving forward since the wing tanks are aft of the CG location.

The CG remained within the stock limits for the accident flight, however, it is possible that the handling characteristics of the airplane changed sufficiently enough due to the modifications that the CG limits were not the same as the stock airplane. There was no testing or evaluation performed to establish acceptable forward and aft CG limits of the modified airplane.

6.0 NAG

The NAG Unlimited Division developed the official competition rules and bylaws that included Aircraft Specifications, Pilot Qualification Specifications, and Technical Inspection Regulations. The most recent version of the rules was adopted in January 2006. There was a provision in the rules for RARA to add aircraft to the end of the qualified list even if they had not successfully completed a qualification attempt in order to complete the field. The rules allowed for this if “the pilot and aircraft have demonstrated their ability to perform at race speed.” The mechanism for demonstrating this was not detailed in the document. The Ghost was entered into the 2010

NCAR under these provisions since there was not a valid qualification run for the airplane. The maximum official race speed that the Ghost reached during the 2010 races was less than 375 mph (326 knots).

One of the special rules listed in Appendix B established an escape route for airplanes that cannot successfully navigate the pylon 7-8-9 turn to the home stretch parallel to runway 8-26. The pilot is allowed to climb to 1500 feet and pass behind the spectator area and rejoin the course east of the runway 26 threshold. There was speculation during the initial stages of the investigation that the Ghost was attempting to utilize this escape route. Examination of the photographic evidence indicates that the pilot was not attempting to utilize the escape route to pass behind the spectator stands prior to the left roll upset.

Appendix C to the Unlimited Division rules established the Aircraft Specifications. The Ghost was allowed to participate in the unlimited division races in 2011 since it presumably met the basic specifications, had the proper FAA licenses and certificates and passed the technical inspection. The P-51D airplane was designed to limit load factors of -4.0 G to +8.0 G and was designed per the accepted structural design criteria of the day and thus met or exceeded the specifications. Specification III C states that aircraft must demonstrate adequate maneuverability (controllability) at racing speed and it can be determined during aircraft qualification. During a 2-lap run on the course in 2010 the Ghost reached a maximum speed of about 425 knots and during a qualification run for the 2011 NCAR the Ghost reached a maximum speed of about 420 knots on the course. During both of these runs there was evidence in the telemetry data that the airplane was exhibiting pitch sensitivity issues at speeds well below the speed recorded during the accident race. For airplanes that are not modified versions of previously designed and built fighter airplanes, the unlimited division specification III D requires that a more rigorous flight test and analysis be performed to substantiate the structural loads, flutter characteristics, weight and balance limits, and flight envelope of the airplane. NAG Unlimited Division specification III D did not apply to the Ghost, however, if it had, the testing likely would have revealed the apparent unstable nature of the accident airplane. NAG should require that any airplane with major modifications also be subjected to the provisions of specification III D as recommended in Safety Recommendation A-12-9.

The technical inspection requirements for the unlimited division are documented in Appendix E. The technical inspection was not meant to be an exhaustive airworthiness inspection of the aircraft, but was intended to catch obvious safety and maintenance issues before the aircraft is allowed to participate in the races. The 2010 technical inspection had several squawks noted on the form and some hand written notes indicating that the crew was not cooperative with the inspectors. Most of the difficulties were due to concerns that the modifications done to the Ghost were going to be communicated to the other race teams by the inspectors. The issues were resolved and the airplane was finally inspected and signed off. The 2011 technical inspection found two squawks on the airplane, one of which concerned the elevator trim tab screws. Interviews established that the squawk was due to the right elevator trim tab screws not having enough threads protruding beyond the nut. This can happen if one of the shorter inboard or outboard attachment screws is installed in the center position or if the screws are cross threaded in the nuts. The specifications indicate that the signature on the inspection form is the approval for the airplane to commence competition. There was no established procedure to document the rectification of the squawks noted on any of the forms but it was established that the items were addressed. The 2011 technical inspection was completed on the airplane on September 12, 2011 and the airplane was approved to race on the course. NAG should develop a system to track any noted discrepancies and their resolution as recommended in Safety Recommendation A-12-10.

7.0 Reno Air Race Association (RARA)

RARA is the overall organizer of the NCAR and provided the Official Rules of Competition for the event in September 2011. The RARA rules established that the class rules would define the eligibility requirements for the aircraft and RARA would conduct the registration of the aircraft for the event. Many of the RARA rules reinforce the Unlimited Division specifications. The RARA rules define the conditional entry process under which the Ghost was entered in the 2010 races. Since the airplane did not establish an official qualifying speed it became a “Conditional Entry to Fill the Field if the Field is not Full by the First Heat Race in its Class”. As such, the Ghost started as the last place aircraft in the lowest heat in the class and worked its way up by winning each of the races to be poised to run the Unlimited Gold race that was cancelled due to winds. In 2011, the Ghost qualified in 4^{th} place in the gold class.

The RARA rules require that any airplane that has had major changes or alterations as defined in FAR 1.1 and 21.93 since the last registration or within the 12 months prior to the races must register and make the aircraft available to the technical inspection committee. Additionally, the airplane must be in compliance with all FAA regulations regarding such changes or alterations. The RARA aircraft data forms include a question regarding the incorporation of any major changes or alterations since the airplane last raced at Reno. The 2009 entry documents for the Ghost have ‘yes’ circled for major changes. Normally, this would flag the entry for an FAA review and for a review by the technical inspection committee. The airplane was not completed before the 2009 races and the entry was cancelled. On the 2010 entry document ‘no’ was circled for major alterations. It is reasonable to assume that Mr. Leeward circled ‘no’ on the 2010 entry since he had previously registered the airplane with ‘yes’ circled in 2009, even though the registration was eventually cancelled when he did not complete the airplane. There was no refund given for the 2009 entry and up until the start of the races Mr. Leeward was attempting to complete the airplane in hopes of participating. The airplane should have been entered as having a major alteration in 2010. The 2009 entry form was faxed from a Comfort Suites hotel in Chicago and received by RARA at or just beyond the deadline for an on time entry. The dates recorded on the form were July 30, 2009, but should have been June 30, 2009.

The RARA pilot entry forms for 2009, 2010, and 2011 were examined and several discrepancies were noted (see Table 2 below). Mr. Leeward listed his age as 59, 59, and 74, his total pilot hours as 13,700, 13,000±, and 13,200±, his years as pilot as 30, 43, and 43, his time in entered race aircraft as 2500+, 2500±, and 2700±, and his time in make and model as 2500+, 2500±, and 2700±. There is no evidence that RARA was aware of the discrepancies on the entry forms.

Year	Age	Total pilot hours	Years as pilot	Entered A/C hours	Make & Model
2009	59	13,700	30	2500+	2500+
2010	59	13,000±	43	2500±	2500±
2011	74	13,200±	43	2700±	2700±

Table 2 – Entry Form Summary

Additionally, RARA requires that documentation of any modifications performed on the aircraft or engine shall be made available to the technical inspection committee of the class. RARA specifically references Federal Air Regulation (FAR) 21.93, FAR 1.1 major alteration and FAR 91.9 for any modifications. Any new aircraft that has not been previously inspected by the technical inspection committee or any aircraft that has had a major change or major alteration per the referenced FARs since the last registration "must register and have their aircraft ready for inspection no later than 1200 hours the first Sunday of race week. All FAA approved documentation must be presented to the Class Tech/Safety Inspection Committee during the inspection of the aircraft." Additionally, if a major change or alteration has been performed since the time the aircraft last raced at Reno or within the 12 months prior to the current race, "all provisions established by the FAA for a major change or alteration, through the FAA Approved Aircraft Operating Limitations, must be accomplished and documented in the aircraft records prior to arrival at Reno/Stead (RTS) and such documentation and related correspondence shall be made available to the FAA and RARA at Pilot Registration."

8.0 Tests & Research

The left elevator trim tab inboard attach screw was found fractured and the tail of the screw remained in the spline nut in the elevator side of the hinge. The screw had evidence of reverse bending fatigue with the final center portion failed in overstress. The hole adjacent to the tail of the screw was also elongated. The corrosion products on the fracture face of the screw indicate that the fatigue fractures had been present for a relatively long period of time. It is unknown if the fractured screw was replaced during the rebuild in 2009. There was a pre-existing fatigue crack in the attach screw present prior to the accident race. The total failure stress required to fracture the screw would be significantly reduced due to the presence of the fatigue cracks. All of the right and left trim tab hinges were examined and all had evidence of relative motion between the hinge halves. The damage included scuffed paint up to fretting of the material. The 4 intact screws were all found to be loose. All of the spline nuts had a fiber locking feature that was worn such that the screws could be inserted using only fingers. The self locking feature on all the elevator trim tab spline nuts was essentially non-existent. Yellow paint on some of the hinges, screws and installed spline nuts indicated that the hardware had been installed on the airplane since at least 1985 when it was painted yellow. All of this information provides evidence that there were oscillatory or vibratory loads on the elevator trim tabs that caused the screws to loosen and allowed relative movement in the hinge halves. In the extreme case on the left elevator trim tab the oscillatory loads were high enough to begin fatigue cracks in the inboard attach screw that propagated over time.

In order for the left and right trim tabs to move to the extreme trailing edge up and down positions noted in some of the photographs, there must be a break in the control system. Based on the information in the NTSB Materials Lab report, the trim tab link assemblies on the accident airplane failed due to buckling under a compressive load prior to ground impact. The force required to buckle a long, slender, hollow, axially loaded column is given by:

$$P_{CR} = \frac{\pi^2 EI}{l^2}$$

Where
P_{CR} = force
l = length of column between restrained ends
E = modulus of elasticity ($30x10^6$ psi for 1025 steel)
I = moment of inertia given by:

$$I = \frac{\pi}{64}\ D^4 - d^4$$

Where D = 0.375 in and d = 0.305 in

So P_{CR} is 1746 pounds for 9.62 inch length and 1791 pounds for 9.5 inch length. The compressive buckling strength of the trim tab control rods is about 1800 pounds.

Flutter is an aeroelastic phenomenon that can occur when an airplane's natural mode of structural vibration couples with the aerodynamic forces to produce a rapid periodic motion, oscillation or vibration. The vibration can be somewhat stable if the natural damping of the structure prevents an increase in the vibratory forces and motions. The motion can become dynamically unstable if the damping is not adequate, resulting in increasing self-excited destructive forces being applied to the structure. Flutter can range from an annoying buzz of a flight control or aerodynamic surface to a violent destructive failure of the structure in a very short period of time. Aircraft speed and structural stiffness are two inputs that govern flutter. As speed is increased or structural stiffness is decreased, the susceptibility to flutter will increase. The loosening of screws leads to a decrease in structural stiffness of the system.

Based on the original documentation for the airplane and the V-n diagram, the stock airplane was designed for 8 G at 8,000 pounds gross weight. If we assume that the 8 G represents a limit load value then the standard 1.5 safety factor yields a 12 G ultimate load capability for the airplane. An estimate of the ultimate capability of the modified Ghost airplane based on the reduced weight and the shortened wingspan can be calculated.

$$G_{mod} = G_{des} \frac{GW_{des}}{GW_{mod}} \frac{Cp_{des}}{Cp_{mod}}$$

$$G_{mod} = 12.0\ G \frac{8000\ lbs}{7765\ lbs} \frac{80\ in}{64.3\ in}$$

$$G_{mod} = 15.4\ G$$

There are other factors that could affect the ultimate load factor capability of the structure. The rapid rise and decrease in the load factor during the upset could also explain the absence of structural failure. Typically, structural damage would be expected to other components of the airplane at flight loads greater than 12 G. For example, the engine mounts could have been substantially damaged as the flight loads increased beyond 12 G. However, due to the extensive impact damage, no determination of flight load-induced damage could be made.

The photos show diagonal wrinkles on the left and right side of the aft fuselage. Most of the photos of the airplane were taken from the left side so there is much more evidence of deformation on this side. The deformation is evident on all 3 laps during the accident race and even in photos taken during the qualifying flights performed on September 13, 2011. The high speeds flown during the accident race put a significant down force on the tail to counter the pitching moment on the wing and actuation of only one trim tab puts an asymmetric load on the empennage. The replacement structure above the upper longeron for the turtle deck and below the lower longeron for the air scoop had different stiffness characteristics than the original structure. The diagonal wrinkling on the aft fuselage is typical for semi-monocoque structures loaded in bending or shear, causing the thin web of skin between the longerons and frames to locally buckle. The buckling occurs in the elastic region so that when the structure is unloaded there is no evidence of buckling remaining. There was no evidence of a load analysis being performed on any of the modified structure. There are instances where structures are designed to have the thin webs buckle under certain loading conditions. For instance many large bombers or transports will have fuselage skins in intermediate diagonal tension while on the ground but it goes away with the application of flight loads. Photos of the other modified P-51 airplanes do not show evidence of the buckling under racing loads. During the accident flight several photos from the valley of speed show a separation between the forward right side of the canopy and the windshield. The canopy deformation should have been evident to the pilot. Both the fuselage and canopy deformation indicate that the airplane may have been operating beyond its structural limits and should have caused the pilot and crew to examine the airplane in more detail.

9.0 Accident Sequence

Based on the video study and the photographs, the airplane was established in a constant left bank of about 73° as it was passing pylon 8. At this point the airplane was flying a circular flight path with a radius of about 6450 feet. The constant bank angle yields a load factor of 3.4 G as defined by:

$$g = \frac{1}{\cos\theta}$$

The telemetry data showed a load factor of about 3.5 G as the airplane was pulling through pylon 8 and just prior to the upset. Between pylons 8 and 9 the airplane entered a left roll upset at 1624:28.90 that caused the bank angle to increase to about 93° in about 0.83 second. At the same time the radius of the airplane flight path decreased which tightened the turn and the pitch attitude of the airplane began to change. The photos show a significant amount of right aileron was input beginning about 0.27 seconds after the initiation of the roll and the airplane then started to roll right out of the left bank. As the airplane rolled right from 93°, the first signs of deformation to the lower engine cowling were evident. At about time 1624:29.46 calculations of angles show that the left elevator trim tab was deflected beyond its up limit of about 13° which can only happen if the trim tab control system is broken. The left elevator trim tab link assembly was failed by 1624:29.46 at the latest. Subsequent photos show the left elevator trim tab in varying positions. At 1624:30.20 the right elevator trim tab was shown in a trailing edge down position. This was the first evidence of the right tab link assembly being failed allowing the fixed right tab to move. The right elevator trim tab link assembly was failed by 1624:30.20, as much as 0.74 seconds after the left tab link assembly failed. The airplane continued to roll right and pitch up. During the maneuver, the video study established that the maximum vertical load factor reached about 17.3 G about 1.3 seconds after the initiation of the left roll upset. The load factor spike remained above 10 G for about 1 second. The maximum load factor and the rate of onset caused the pilot to become incapacitated within about 1 second of the initiation of the left roll upset. The airplane was no longer being controlled by the pilot early in the sequence. As the airplane was pitching up and experiencing an increasing load factor the tail wheel extended and the lower engine cowling exhibited increasing evidence of buckling. The photographs show that at 1624:32 the left elevator trim tab was still intact and less than a second later the first of 3 photos showed the tab in the process of separating from the airplane. The inboard portion of the left trim tab departed the airplane as it was inverted and heading away from the race course. The separation of the left elevator trim tab occurred at least 4.5 seconds after the initiation of the left roll upset. The airplane impacted the ground about 4.5 seconds after the separation of the left elevator trim tab section and about 8 seconds after the initiation of the left roll upset.

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