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Report A-027/2010

Accident involving a Zivko Edge 540 aircraft, registration N-540WC, in the vicinity of the Casarrubios Aerodrome (Toledo), on 17 August 2010

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MINISTERIO DE FOMENTO

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Foreword

This report is a technical document that reflects the point of view of the Civil Aviation Accident and Incident Investigation Commission (CIAIAC) regarding the circumstances of the accident object of the investigation, and its probable causes and consequences.

In accordance with the provisions in Article 5.4.1 of Annex 13 of the International Civil Aviation Convention; and with articles 5.5 of Regulation (UE) n° 996/2010, of the European Parliament and the Council, of 20 October 2010; Article 15 of Law 21/2003 on Air Safety and articles 1, 4 and 21.2 of Regulation 389/1998, this investigation is exclusively of a technical nature, and its objective is the prevention of future civil aviation accidents and incidents by issuing, if necessary, safety recommendations to prevent from their reoccurrence. The investigation is not pointed to establish blame or liability whatsoever, and it's not prejudging the possible decision taken by the judicial authorities. Therefore, and according to above norms and regulations, the investigation was carried out using procedures not necessarily subject to the guarantees and rights usually used for the evidences in a judicial process.

Consequently, any use of this report for purposes other than that of preventing future accidents may lead to erroneous conclusions or interpretations.

This report was originally issued in Spanish. This English translation is provided for information purposes only.

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Abbreviations

00°	Degrees
00 °C	Degrees centigrade
ADF	Automatic Directional Finder
AMT	Aviation Maintenance Technician
CIAIAC	Comisión de Investigación de Accidentes e Incidentes de Aviación Civil
CPL(A)	Commercial Pilot License (Airplane)
EDM	Engine Data Management.
EFIS	Electronic Flight Instruments System
EM	Engine Monitoring
EMS	Engine Management System
FAA	Federal Aviation Administration
ft	Feet
G	Acceleration due to Earth's gravity
G-LOC	Loss of Consciousness due to G's
h	Hours
hPa	Hectopascal(s)
HSI	Horizontal Situation Indicator
IFR	Instrument Flight Rules
kg	Kilogram(s)
kt	Knot(s)
lb	Pound(s)
LEMT	ICAO designator for Casarrubios del Monte Aerodrome
m	Meter(s)
N	North
N/A	Not applicable
NOTAM	Notice To Airmen
NTSB	National Transportation Safety Board (U.S.A.)
PFD	Primary Flight Display
QNH	Atmospheric Pressure at Nautical Height ; Qcode designation for atmospheric pressure at mean sea level
S/N	Serial number
SE	SouthEast
sec	Seconds
UTC	Coordinated Universal Time
W	West

Synopsis

Owner and operator:	Private
Aircraft:	Zivko Edge 540, S/N 0028; registration N-540WC
Date and time of accident:	17 August 2010, at 10:35 UTC[1]
Site of accident:	"La Solana" Ranch. Vicinity of the Casarrubios Aerodrome (LEMT), within the aerobatic box[2]
Persons onboard:	1, killed
Type of flight:	General aviation – Other – Airshow – Training flight
Date of approval:	25 January 2012

Summary of accident

On 17 August 2010, at around 10:35 (UTC), the pilot of an Edge 540 aircraft, registration N540WC, was conducting training maneuvers for an airshow that was scheduled for two weeks later. The pilot had performed several maneuvers already, the last of which was called a snap roll[3]. Normally, the pilot would execute two or three rolls before recovering, but this time he continued to roll. As a result, the AMT, who performed maintenance on the aircraft and who was watching the maneuver from the ground, immediately tried to warn the pilot to recover from the maneuver. The aircraft continued rolling and crashed into the ground.

The pilot was killed as a result of the impact and the aircraft was destroyed.

An analysis of the information gathered during the investigation resulted in the formulation of three probable causes of the accident: one involves a possible miscalculation of the altitude at the start of the maneuver and other two relate to the physical or physiological inability of the pilot to recover from the roll.

Although the main cause of the accident could not be determined, it is believed to have been caused by:

- An improper estimate of the starting altitude for a descending snap roll maneuver below that required to ensure the number of rolls the pilot wished to execute,

[1] All times in this report are in UTC. To obtain local time, add two hours to UTC.
[2] Aerobatic box- imaginary box within which aerobatic maneuvers are performed, in this case to ensure the safety of both the aircraft performing the maneuvers as well as of all other traffic using the airfield.
[3] This maneuver is also known as a "flick roll". See Note 4.

- A loss of consciousness that momentarily incapacitated the pilot, preventing him from exiting the maneuver in time or by
- The presence of a physical or mechanical obstacle or impediment, possibly involving the use of the pedals, that restricted or prevented the pilot from controlling the aircraft.

1. FACTUAL INFORMATION

1.1. History of the flight

The pilot was doing acrobatic maneuvers in preparation for an airshow scheduled in the weeks to come. He had performed similar training maneuvers two days before the accident. This was the first flight of the day. He normally trained for ten minutes and at the time of the accident, he had been in the air for six or seven minutes. As a result, the AMT, who was watching the practice session from the ground, stated that it was probably not the final maneuver the pilot planned to perform. The pilot had not yet decided on the exact sequence of maneuvers he would perform at the airshow. After doing various maneuvers, the pilot initiated a snap roll[4], presumably to the right, at 45° and descending. Judging by the initial altitude, the eyewitness expected the pilot to roll two or three times, as was his normal routine, but on this occasion the pilot continued, making six or seven rolls. The AMT radioed the pilot to warn him but did not receive a reply. The aircraft impacted the ground. The pilot died as a result of the impact and the aircraft was destroyed.

1.2. Injuries to persons

Injuries	Crew	Passengers	Total in the aircraft	Others
Fatal	1		1	
Serious				
Minor				Not applicable
None				Not applicable
TOTAL	1		1	

1.3. Damage to aircraft

The aircraft was destroyed as a result of the impact. The specific damage is listed in Section 1.10 Wreckage and impact information.

1.4. Personnel information

The 41-year old pilot, a Spanish national, had a commercial pilot license (CPL) with single-engine and multi-engine land ratings issued by the authorities of the United States

[4] Maneuver that consists of quickly rolling the aircraft under power using only the rudder. Different combinations are possible: vertical, horizontal or at 45°, climbing or descending, from positive or negative and turning left or right. Several rolls/turns can also be linked together in a single maneuver to make it more spectacular. When a smoke system is used, this maneuver makes the smoke trail look like a telephone cord.

(FAA[5]), as well as an instrument (IFR) rating, all valid and in force. He also had a valid and in force class-2 medical certificate.

The pilot logbook had entries from August to September 2006, and then from April to November 2009, meaning it was impossible to ascertain the total number of flight hours, as well as the number of hours flown specifically on this type of aircraft. According to the entries in the pilot's logbook, from April to November 2009, he had flown a total of 100 h, 20 of them on the accident aircraft, approximately the same as he flew in 2010 (based on information obtained during the investigation). According to the data in the aircraft logbook, when contrasted against the information in the pilot logbook, the pilot had approximately 3,700 total flight hours, 200 on this aircraft type.

The pilot was highly experienced in aerobatic flight, having twice been the champion of Spain, though in recent years he had devoted himself almost exclusively to competing in the Red Bull Air Race[6], which he had started in 2003. The accident aircraft was the same used by the pilot while competing in races between 2005 and 2007. Since late 2007, the pilot had flown another racing airplane, an MXS-R, in an effort to be more competitive. Unlike in aerobatic flying, where precision is paramount, these races favor mostly high speed and low altitude flying, in addition to accuracy when crossing the gates with the airplane in a specific attitude. The G's reached in these races are very high due to the sharp turns and speed increases, which require that the pilots wear special anti-G suits and boots[7]. In aerobatic flight these suits are not usually worn since the G's attained are not as high. At the time of the accident the pilot was wearing sneakers and clothing. His foot size was 45 (11" and 12"), he stood 1.80 m tall and weighed about 90 kg. He was held to the aircraft seat by a five-point harness, which also held a backpack with a parachute. He was not wearing a helmet, but he did have headphones on to communicate.

1.5. Aircraft information

1.5.1. *General information*

The accident aircraft was a ZIVKO EDGE 540, registration N540WC and serial number (S/N) 0028. It had been built in 2001 and, judging by the registration date, was purchased in late 2005. It was a single-seat, aerobatic aircraft consisting of a steel tube fuselage and composite wings, tail and fairings. It was outfitted with an experimental Lycoming AEIO-540-EXP engine, S/N L-50690-01, and with an MTV-9-B-C/203-20d propeller, S/N 090304. The roll rate of this aircraft model is 420°/sec and it can withstand up to 12 G's of vertical acceleration.

[5] FAA – Federal Aviation Administration.

[6] Red Bull Air Race (RBAR) – International competition of single-seater acrobatic aircraft in which the pilots must fly through several inflatable pylons arranged in pairs (gates) and fly the circuit as precisely and as fast as possible.

[7] The purpose of an anti-G suit is to protect racing pilots from the debilitating forces that arise when maneuvering between gates, and particularly during high speed turns around the circuit. These forces can be as high as 12 G.

Figure 1. Picture of the accident airplane

The entries in the aircraft logbook revealed that the last annual inspection was performed in January 2010, with 548 h on the airplane. Since that inspection, the aircraft would have been flown an additional 20 hours, based on information gathered during the investigation.

The aircraft had a registration certificate issued in October 2005 and a special airworthiness certificate issued in July 2003 with no expiration date. Both had been issued by the authority in the United States (FAA). The aircraft also had an Aircraft Station License certificate and the insurance certificate was valid until 27 September 2010.

1.5.2. *Primary characteristics of a racing aircraft and comparison of the two models used by the pilot*

The control surfaces of a racing aircraft (ailerons/rudder/elevator) are relatively large, which makes them more effective and responsive. They are also, therefore, extremely sensitive to any control inputs. The ailerons have "spades" that are used to reduce the force needed to deploy them. The elevator and ailerons are controlled by means of pushrods, and the rudder by a steel cable. In this particular aircraft, a second steel cable had been installed at the pilot's request following an accident[8] he had had in another aircraft as a result of a failure of this cable.

[8] See: http://www.fomento.gob.es/MFOM/LANG_CASTELLANO/ORGANOS_COLEGIADOS/CIAIAC/INVESTIGACION/2001/2001_010_A-pdf.htm

The fuselages of racing aircraft are made of tubular steel structures. In general, the fairings are designed to weigh as little as possible.

These aircraft have a fixed landing gear, with hydraulically actuated brake disks. These aircraft are normally of the tail skid variety, which allows them to turn quickly on the ground.

They have three fuel tanks, two in the wings, which are not used during aerobatic flight, and the fuselage tank located between the cockpit and the engine, which is used during aerobatic flight.

These aircraft have low-weight smoke systems that, when activated, show the aircraft's trajectory.

The pilots wear special helmets with a visor, a fire-resistant suit, flight gloves, boots and a parachute.

The five-point safety harness also features a ratchet system, which in effect makes it a highly adjustable seven-point harness. These systems have a quick-release mechanism for rapidly unbuckling the harness should it be necessary to jump from the aircraft.

A comparison of the two aircraft models used by the accident pilot reveals a notable difference in the cockpits: the tubular structure is visible in the Edge 540, while a panel restricts direct access to the structure in the MXS-R. The design of the rudder pedals is also very different (see Figure 2).

The seatback in a racing airplane is generally sloped back due to the large vertical acceleration experienced by pilots in competition (on the order of +11G to –9G). With the pilot almost supine, the amount of blood that in upright position would be sent to

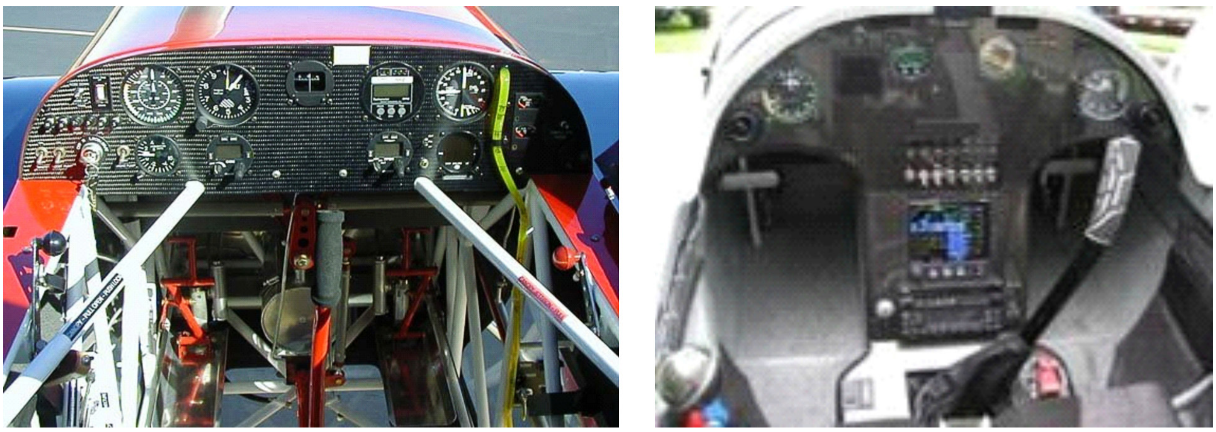


Figure 2. Comparison of the cockpit interior in two aircraft similar to those used by the pilot (Edge 540 and MXS-R)

the extremities and away from the brain is reduced. Under these conditions, it is most unlikely that the pilot to gray out, then lose his vision before finally losing consciousness, or G-LOC[9].

These aircraft are normally equipped with an Electronic Flight Instrument System (EFIS) that shows several kinds of information to the pilot, such as speed, instantaneous G forces, times by sector and lap times, as well as instructions from the race director, etc. Under normal conditions it is used with the Primary Flight Display (PFD), Horizontal Situation Indicator (HSI) and Engine Management (EM) functions. This screen shows altitude information. When this screen was installed on the accident aircraft, the barometric altimeter had to be removed due to space constraints.

The accident aircraft also had an engine data management system (EDM 930) that stored the data associated with various engine parameters.

The pilot would download the EDM and EFIS data after a flight to analyze his performance.

1.6. Meteorological information

Although data from the aerodrome where the accident took place were not available, based on data recorded at the Getafe and Cuatro Vientos aerodromes, synoptic maps, satellite, radar and electric discharge images, and survey data from Barajas, the most likely weather at the site of the accident for the interval from 08:00 to 12:00 was as follows:

- Calm surface winds (below 4 kt) from variable direction. Winds aloft from the SE reaching 11 kt at an altitude of 5,000 m.
- Good visibility on the ground.
- Cloudy skies with cloud bottoms at an altitude of about 3,000 to 4,500 ft.
- Temperature on the ground between 20 and 26 °C.
- There was no precipitation or storm activity in the interval in question.
- QNH between 1,020 and 1,021 hPa.

Eyewitness accounts also indicate it was a clear summer day with barely any wind.

1.7. Communications

Since the aerodrome was not controlled, there were no communications in terms of aircraft clearances. Nevertheless, the mechanic and pilot were able to communicate via

[9] G-LOC Loss of Consciousness due to G's.

radio (the mechanic had a walkie-talkie). On this occasion, they communicated during the takeoff, though they did not talk on the radio during the training maneuvers nor was there any reply when the mechanic attempted to warn the pilot to pull out of the maneuver.

1.8. Aerodrome information

The Casarrubios Aerodrome is a private airfield located in the province of Toledo at coordinates 40° 14′ 06″ N / 04° 01′ 53″ W and an elevation of 2,050 ft. It has a 1,000-m long, 26-m wide paved runway in a 08/26 orientation. Within this aerodrome's airspace is an aerobatic box consisting of an imaginary cube whose limits and altitude are specified in a NOTAM. Aerobatic maneuvers are performed inside this box, which is itself within another box called the safety area. Normally the aerobatic box is used as a reference by judges in aerobatic competitions. At this aerodrome, the box is intended to ensure the safety of both the aircraft performing aerobatic maneuvers and of other traffic using the airfield (see Figure 3). Aerodrome procedures define the method to be used by traffic using the airfield to make approaches, takeoffs and landings when the aerobatic box is active; that is, when an aircraft is going to be performing aerobatic maneuvers within the box.

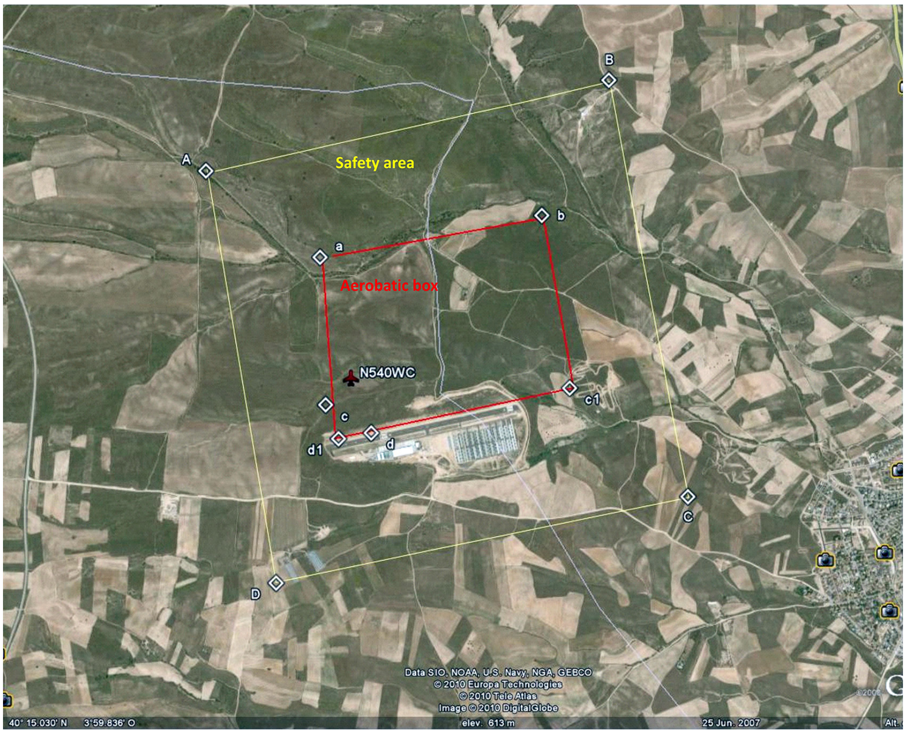


Figure 3. Aerial view of the Casarrubios Aerodrome (LEMT), showing the aerobatic box and the safety area

1.9. Flight recorders

Flight recorders were not installed or required on this aircraft type.

However, since the pilot had previously raced in this aircraft, there was an Electronic Flight Instrument System (EFIS) onboard that the pilot used to monitor and improve his maneuvers. The aircraft also featured another system, the EDM 930, which monitored engine parameters. Both systems relied on memory chips to store data for various parameters. Unfortunately, although the cards were recovered from the wreckage, repeated attempts to locate the chips were unsuccessful, as the chips had been ejected from their respective housings. As a result, precise engine, altitude and trajectory data were unavailable to investigators when they attempted to reconstruct the aircraft's exact trajectory.

1.10. Wreckage and impact information

The aircraft wreckage was found by the south side of the runway, in a ranch adjacent to the aerodrome and within the aerobatic box (see Figure 3). There was an initial impact mark followed by debris from components and the fuselage and finally the main wreckage some 25 m away from the initial mark. The debris field indicated that the aircraft was on a heading of about 60° with respect to magnetic north, and that its nose was oriented at 150°.

The following were found at the impact site: a small piece from the bottom section of the rudder, corresponding marks on the ground (probably from the aircraft's wheels), the ADF antenna and the bar from the left spade, which had dug into the ground. Further along in the debris field were the links from the elevator control bar with the lower part of the pilot's seat, as well as structural beams (probably from the underside of the cockpit), various fairing fragments, different engine components (starter, carburetor throttle with part of the carburetor), the crankcase and battery fragments.

The spring landing gear was found attached to the main wreckage. The part where the wheels connected to the fuselage was bent backwards. The landing gear wheels had detached, with the right wheel being found some 70 m left of the main wreckage. The left wheel, which was still joined to its fairing, was also to the left of the wreckage. Both wheel rims had been compressed and had a clearly visible oval shape, though the tires were still pressurized.

Practically the entire aircraft was found within the main debris field.

The three-blade propeller showed clear signs of having impacted the ground under power. Splinters from one of the blades and another large piece were found a few meters away and to the right of the main wreckage.

The engine was still attached to the main wreckage, though it had shifted to the rear and impacted the main spar, destroying the fuel tank located in the fuselage, which was bent upward due to the compression force exerted by the engine against the cockpit. The fuel tanks located in the leading edges of the wings were also damaged.

The main wing spar was in one piece and a large part of the wing's aerodynamic profile was still attached to it.

In the cockpit the instrument panel was broken and the instruments had been ejected. The anemometer was detached from its position and damaged. The needle read 150 kts. The components that comprised the EFIS display were found to the left of the cockpit, along with the electronic boards from the EDM system.

Also found fragmented and detached was the roll torsion tube (which has an anchor point for the safety harness at its rear support). The cable used to anchor the right shoulder position on the safety harness was also broken.

The aileron connecting links exhibited continuity from the main link to the ailerons.

The rear of the fuselage to the tail section was bent downward. For the most part, both the horizontal and vertical stabilizers retained their structural integrity. Only the counterweights housed at the tips of the horizontal stabilizer had been ejected by the inertia of the impact.

The rudder was detached and located underneath the right wing, which indicates that it was subjected to heavy aerodynamic loads at the time it impacted the ground. The elevator was intact, though the linkages between the central section and the control bar in the cockpit were found fragmented all along the impact trajectory.

The travel of the elevator control was subsequently reconstructed in a hangar and it was determined that the fractures and warping had resulted from the impact with the ground.

The right pedal was attached to the rudder via a dual cable. The left had been cut by emergency personnel in their efforts to extract the pilot.

Judging by the impact marks and wreckage, the aircraft impacted in a level attitude, with a slight bank to the left but at high speed. Considering the aircraft's final position and the condition of the wreckage, the impact probably had a large vertical component and took place once the aircraft had practically completed the maneuver. Due to this high energy, the gear leaf spring bent, resulting in the airplane's belly hitting the ground and leading to the downward deformation that was evident in the rear of the fuselage and tail section, as well as to the detachment of the landing gear wheels. After this initial impact, the aircraft was propelled to the final position in which the wreckage was found since there is no evidence that the structure traveled along the ground.

1.11. Medical and pathological information

The medical examiner's autopsy report concluded that the primary cause of the pilot's death was multiple trauma, with the immediate cause being the destruction of vital nerve centers and organs.

The toxicological analysis performed on the pilot did not reveal any substances of toxicological significance.

1.12. Fire

There was no fire after the impact.

1.13. Survival aspects

Given the nature of the accident, there was no possibility that the aircraft's occupant could have survived.

1.14. Tests and research

Due to the peculiar interior structure of the cockpit with its accessible tubular structure, and to reports in other cases of said structure potentially interfering with the pilot's feet (see Section 1.15.3), a test was conducted inside another similar aircraft[10]. The test attempted to simulate potential interference scenarios between the tubular structure and the feet of a pilot who was executing a maneuver like that involved in this accident. The results were inconclusive. It was not difficult to move the feet away from the pedals, but it was hard to determine where the foot might have gotten stuck. There was a space in which the foot could be inserted, but not one in which the foot could be trapped once the pedal, which was not blocked, was moved, thus returning the foot to its original position. Even so, it was impossible to reproduce the identical scenario present in this accident. The pilot's particular body structure (tall, stocky and with a large foot size), adjusting the seat to his size, as well as the fact of having two cables connecting the pedals to the rudder, mean that there were more factors involved in the events leading up to the accident than could be accurately reproduced in the test.

[10] Since a similar aircraft was not available in Spain, this test was conducted by an NTSB investigator at the manufacturer's facilities at the CIAIAC's request.

1.15. Additional information

1.15.1. *Eyewitness statements*

One of the eyewitnesses to the accident was the aircraft maintenance technician (AMT) responsible for the aircraft in question and member, along with the pilot, of the Red Bull Air Race team. The AMT was outside the hangar, which is on the south side of and parallel to the runway. According to his statement, he did not have a coach, since he barely did aerobatics and was involved in the Red Bull championship races, which rely more on fast and accurate maneuvers than on aerobatics. The AMT had a walkie-talkie to keep in contact with the pilot in case there was a problem or the pilot needed something specific, but normally the AMT was inside the hangar. However on the day of the accident he was outside the hangar, watching the practice. The pilot had been flying for six or seven minutes and had performed several maneuvers, though the accident maneuver did not appear to be the last one planned. His training sessions usually lasted about ten minutes. They had discussed lowering the altitude of the maneuvers. He still had not worked out the maneuvers he planned to perform, and that day he had done a tumble, a loop, a four-point hesitation roll, a hammerhead turn and a Cuban eight. It was while exiting from this maneuver when, at 45° from the horizontal, he started performing a series of fast barrel rolls. The AMT thought that in light of the altitude at which he had started, that he would do two or three rolls, but when he started the fourth the AMT quickly stood up and warned the pilot over the radio to pull out of the maneuver. That day he had not performed the same maneuver and his previous training run had been two days before the accident. According to the eyewitness there was no abnormality in the maneuver or in the engine noise.

Another eyewitness to the accident was close to the first observer when he saw the last part of the maneuver, as he was approaching to the first eyewitness. He also noted nothing unusual in the flight path or in the engine sound until the aircraft impacted the ground, after which he heard two "thuds".

1.15.2. *Description and execution of the snap roll maneuver*

This maneuver starts with quick pitch and yaw motions that cause one wing to momentarily stall while the other maintains lift. The maneuver is performed under power. There are different types of rolls, depending on the combination: vertical, horizontal or at 45°, climbing or diving, from positive or negative and turning left or right. Several rolls and turns can also be stringed into a single maneuver to make it more spectacular. In this particular case, the maneuver involved a 45° dive while turning to the right. This is performed as follows: the stick is pulled back to cause a stall and the airplane is placed at a 45° up angle. This is normally initiated at 3000 ft and ends at 1,000 ft, depending on the number of turns to be made, with approximately 150 ft being lost per roll. This maneuver involves mainly the use of the rudder, with the pedal on the side to which the turn is to be executed being fully depressed. To recover from the maneuver, the opposite pedal is applied, with the angle of attack being maintained with the stick. If the smoke system is used, this maneuver looks like a coiled telephone cord (see Figure 4). The aircraft's nose comes out on the same trajectory. This maneuver is performed very fast, and the amount of inertia accumulated by the aircraft as a result of the turns can result in the aircraft rotating an additional 1/4 roll approximately.

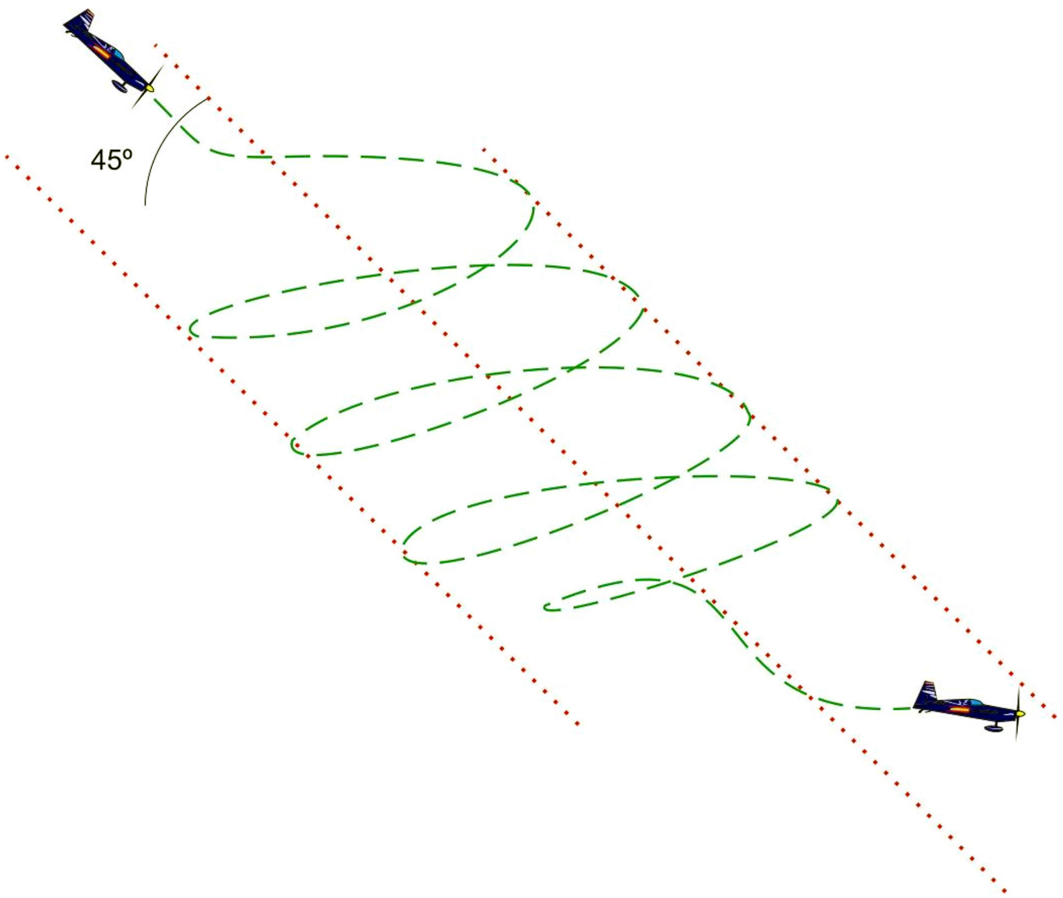


Figure 4. Snap roll maneuver with four consecutive turns at 45° descending and positive

1.15.3. *Previous events involving this aircraft model*

In August 2009 during an aerial competition, a similar aircraft flew into the ground while performing a snap roll[11]. The pilot died as a result of the impact. The investigation revealed that the pilot, due to her small stature, relied on extensions to reach the rudder pedals, and that their design and set-up could have impeded the pedal motion required to recover from the maneuver.

[11] See: http://www.aaib.gov.uk/publications/bulletins/september_2010/zivko_aeronautics_inc_edge_540__n540bw.cfm

The information gathered over the course of this accident investigation revealed testimony from three witnesses whose feet had become entangled on the pedals when performing this maneuver.

One of the pilots who experienced this also relied on pedal extensions. At first, when he was new to the aircraft and during his first flight with the extensions in place, as he depressed the left pedal fully, his right heel moved back (under the foot support). The pilot was unable to stop the rotation until he lifted his foot and applied right pedal, since his heel was trapped by the tubular structure and the bottom of his foot was resting on the support, which prevented him from applying right pedal. Once he lifted his foot and applied the pedal, the rotation stopped immediately and he was able to recover from the maneuver, though for a few seconds he involuntarily performed one or two more turns than he was planning to at the start of the maneuver.

Another pilot, who did not use extensions, noted that performing negative-G aerobatic maneuvers could cause his foot to become stuck, since the negative G forces would cause his foot to move up, resulting in the toe of this shoe getting trapped under the main spar or within other obstacles in the cockpit's tubular structure (see Figure 5).

This pilot nevertheless thought that he could release his foot if that happened, though it would require some time. He also regarded this as a normal and well-known scenario in aerobatics, and that many pilots opted to install straps to attach the feet to the pedals so as to avoid these situations. He also stated that the turn rate during a snap roll could be very high (over 400°/sec), which means that the pilot would not be able to look outside with ease and that the ground reference would be hard to judge. Also, while performing downward rolls the descent rate would be very high and one more roll could mean not having enough space to pull out of the maneuver.

Figure 5. Areas near the pedals where the feet can become entangled

The last witness, a pilot who did not use extensions either, related that he was in a practice flight doing a left downward snap roll and that he planned to execute two turns. He started by placing the aircraft into a vertical descent. After a second (at about 120 kt), he applied full left pedal and elevator to start the negative snap roll. After one and a half turns, as he tried to recover from the maneuver (full opposite pedal and heading as required), the pilot's right foot slid down into the gap between the pedals. The foot was trapped in this small area and he had to tear his shoe until he was able to free his foot, at which time he was able to recover from the maneuver and arrest the descent just 30 m (100 ft) before impact. Normally this maneuver is terminated at 300 m (1,000 ft).

The aircraft manufacturer was asked about previous incidents of this nature and assured that since production started on the Edge 540 in 1993, it was unaware of any incidents in which a foot had been trapped between the pedals and the main spar.

1.15.4. *G's during aerobatic flight*[12]

During aerobatic maneuvers, the human body is subjected to the physiological effects associated with high acceleration (G) forces. The forces involved in a rapid free fall maneuver will cause the blood and organs to shift toward the head (negative G forces). Depending on the forces involved and the individual's tolerance, a pilot may experience discomfort, headache, red out or even lose consciousness.

The forces associated with a rapid climbing maneuver will cause blood and the organs to shift downward, away from the head (positive G force). Since the brain requires a constant flow of blood to supply it with oxygen, there is a physiological limit to how high a G-force a pilot can withstand before losing consciousness. As the forces involved cause the blood flow to the brain to decrease, a pilot will experience tunnel vision, gray-out, black-out and loss of consciousness (G-LOC). Even a brief loss of consciousness during a maneuver can lead to an improper control input, causing the aircraft to fail structurally or to impact another object or the ground.

During loops, the centrifugal forces can push the pilot into the seat, causing the blood and body organs to shift down in the body, as happens with quick climb maneuvers and resulting in the same physiological effects and symptoms.

Physiologically, human beings gradually adapt to repeated pressures or stresses and with practice, a maneuver's effects will lessen. The tolerance to G forces depends on human physiology and on the individual pilot. These factors include the anatomy of the skeleton, the cardiovascular structure, the nervous system, the condition of the blood, the overall physical state and the time since the last exposure.

[12] "G Effects on the Pilot During Aerobatics", FAA-AM-72-28, and "G Incapacitation in Aerobatic Pilots: A Flight Hazard" FAA-AM-82-13.

Based on the findings of the study conducted by the FAA[13] on the historical perspectives of aerobatics and the physiological effects of G acceleration (especially as pertain to in-flight loss of consciousness (LOC) by the pilot), historical evidence suggests that human beings have a variable but limited tolerance to G's, a tolerance that if exceeded can cause an individual to lose consciousness. If the pilot experiences G-LOC during flight, this condition can last an average of 15 seconds, followed by another 5 to 15 seconds of confusion and disorientation. The G's involved in acrobatics are generally within the same range as those that cause LOC in centrifugal force studies in humans.

Aerobatic maneuvers, such as the vertical inside-outside Cuban eight, subject the pilot to sudden changes from negative to positive G's, a transition that the cardiovascular system seems to have the most difficulty compensating for. The pilot is most likely to experience G-LOC during this maneuver.

In the accident at hand, the maneuver immediately prior to the accident maneuver was a horizontal Cuban eight that, though to a lesser extent than the vertical, also subjects the pilot to large swings from negative to positive acceleration.

[13] FAA-AM-82-13 G Incapacitation in aerobatic pilots: a flight hazard.

2. ANALYSIS

2.1. General

The pilot had extensive experience in performing aerobatic maneuvers, though in recent years he had been more involved in participating in the Red Bull Air Race competition, though he occasionally practiced aerobatics and performed in air shows. The two types of flying activities (racing versus aerobatics) involve different skills: racing requires speed, low-altitude flying and executing standard and repetitive maneuvers, whereas aerobatics features more diverse maneuvers carried out at a higher safety altitude, though during an air show they are made more spectacular by performing them closer to the ground. This serves to underscore that the altitude references were not those typically encountered by a pilot accustomed to doing low-altitude flights.

There are also certain differences between the aircraft available to the pilot and the purpose (aerobatics or racing) for which they were going to be used. The difference in terms of the cockpit design could pose a challenge. When the pilot raced the accident aircraft he used the proper equipment, including boots (stiffer footwear). The change involved in using this same aircraft to practice aerobatics while wearing different gear could have meant that the pilot faced slightly different conditions when engaged in this activity.

2.2. Hypotheses considered

Based on the information gathered and its analysis and study during the investigation, three hypotheses were considered in an effort to explain the cause of the accident:

2.2.1. *First hypothesis – Reference altitude at start of maneuver*

The first hypothesis considers the possibility that the pilot did not notice the reference altitude at the start of the maneuver in relation to the number of turns/rolls he planned to make, or that he wanted to make them at a low altitude to maximize the spectacle. It must be remembered, on the one hand, that the aerodrome where the accident took place was the one normally used by the pilot, meaning that the reference altitudes above ground level, in addition to having been displayed on the altimeter (information shown on EFIS) were known to him. There is, on the other hand, an inherent drawback to being familiar with the airfield in that it could give rise to an excessive amount of confidence in the pilot in surmising those altitudes and not checking the reference altitude on the EFIS display. The last maneuver performed was not his first. According to the eyewitness, after performing several maneuvers, the pilot had just finished executing a horizontal Cuban eight, which he segued into the accident maneuver, meaning there might have been a drop in altitude that was unnoticed by the pilot.

Considering that the aircraft did 6-7 turns, the altitude at the start of the maneuver can be estimated to have been 1,000-1,200 ft, assuming a rough calculation using the typical parameters involved in the maneuver. The maneuver, however, picks up speed at it progresses, so it is impossible to determine the altitude lost with each roll as well as the number of rolls the pilot did or, most importantly, how many rolls the pilot had intended to execute. The information stored in the EFIS memory chips could have shed some light on the reference altitude at which the pilot started the maneuver, though the number of rolls the pilot planned to do would still be unknown.

The pilot had flown aerobatic maneuvers two days earlier and by the date of the accident, he still had not decided exactly what aerobatic maneuvers he would perform. He had planned to do them at a lower altitude, but considering he still had not finalized his program, it does not seem logical that in that flight he would start the maneuvers at a lower altitude.

According to information provided by the AMT, who was used to watching the pilot's maneuvers, he usually did 3 or 4 turns/rolls at the most, judging by the altitude at which he had started. When he continued with the maneuver, the AMT sensed that something was wrong and radioed the pilot to pull out of the maneuver, to no avail. It does not seem logical for the pilot to have ignored his AMT's warning, though the possibility that the pilot incorrectly estimated the reference altitude at the start of the maneuver cannot be ruled out.

2.2.2. *Second hypothesis – Possible loss of consciousness*

The next hypothesis considers the possibility that the pilot experienced some kind of physical difficulty. A loss of consciousness, even if it only lasted seconds, would have resulted in more turns being executed and in the airplane impacting the ground. The negative G forces involved in the maneuver could have led to a loss of consciousness or in a temporary inability to reason and to remain aware of the right time in which to pull out of the maneuver. The pilot was used to wearing an anti-G suit and boots to help him withstand the high acceleration forces involved in racing, and on this occasion he was not wearing this gear. Another consideration is the fact that the G forces experienced in aerobatics are not as high as those associated with racing (which involves high speeds and sharp, sudden turns) and the pilot had experience with these kinds of maneuvers. Another fact to consider is that the two eyewitnesses who saw the accident from practically the same vantage point did not observe any abnormalities in the flight path. Had the pilot momentarily lost consciousness, the loss of input to the control stick (elevator and ailerons) would have resulted in the execution of a strange maneuver that would have been noticed by observers on the ground.

Even so, the pilot had just finished doing several maneuvers, including a horizontal Cuban eight, and been subjected to large swings from positive to negative G's (see

Section 1.15.4). This, added to the pilot's lack of activity performing maneuvers without the use of an anti-G suit, could have made him more susceptible and lowered his tolerance to these changes.

As a result, a possible temporary loss of consciousness during the performance of the aerobatic maneuver cannot be ruled out.

2.2.3. *Third hypothesis – Restriction in rudder movement*

The third hypothesis considers the possibility that there was some kind of physical/mechanical impediment that prevented the pilot from ending the maneuver in time. This maneuver is initiated and terminated almost exclusively with rudder pedal inputs. The accounts received regarding the possibility that the tubular structure, which is accessible from the inside of the cockpit, could have hindered the motion of the pilot's feet give credence to this possibility. The pilot was a tall, stocky man who wore a large shoe size. The negative G forces could have forced the feet away from the pedal support, resulting in some part of the foot becoming trapped in the tubular structure or in the pedal structure. Some pilots have resorted to using straps to attach their feet to the pedals to keep the feet and pedals from separating. This approach, however, must also take into account the fact that the safety harness has a quick-release system so that, in the event of an emergency, the pilot can quickly exit the aircraft, in which case the foot straps would hinder the pilot's egress. The aircraft to which the pilot had become accustomed to flying in recent years looked significantly different from that used in the accident flight. The interior panels in the cockpit in the former prevent any interference with the feet. Even the pedals were designed differently to avoid such an occurrence. The use of an aircraft different from that to which the pilot was accustomed, along with the fact that the footwear used during the accident flight (sneakers, more flexible) instead of those ones worn in the other aircraft, or even in the same aircraft when used for racing (more rigid boots), could have resulted in interference with or restriction in the movement of the pedals when the pilot attempted to recover from the maneuver. The aircraft wreckage and its arrangement indicate that the pilot had just pulled out of the maneuver, since the aircraft was not turning and the aircraft impacted with a large amount of vertical energy. Had one of the pilot's feet become stuck and been unable to apply opposite pedal pressure to recover from the maneuver, the aircraft would have continued executing the maneuver (with full pedal pressure) at an ever increasing speed. To an observer on the ground, this would have resulted in a continuous and clean trajectory, and thus this too is a feasible hypothesis.

3. CONCLUSION

3.1. Findings

The information available and its analysis have led to the following findings:

- The pilot was qualified and had extensive experience performing aerobatic flights and maneuvers.
- The aircraft was suited to the performance of aerobatic flights and had passed its maintenance inspection.
- The pilot was practicing aerobatic maneuvers for an upcoming air show.
- The pilot had devoted himself in recent years to a considerably different discipline (racing), though he continued to do purely aerobatic flights.
- The pilot had conducted a similar aerobatic flight two days before the accident.
- The pilot's clothing was not ideal and differed from that typically worn by him during races and which he usually wore when flying that aircraft.
- The accident aircraft had been used by the pilot in the years before he switched to racing, but he used an anti-G suit.
- At the time of the accident he was more accustomed to another aircraft that he used for racing.
- The two aircraft were different in terms of the inside of the cockpit. The accident aircraft had an accessible tubular structure while in the racing aircraft, this structure was covered by a panel, preventing the access to the tubular structure.
- The pilot had planned to do the maneuvers at a lower altitude to make them more spectacular during the air show.
- The pilot had not yet defined the specific program he was going to fly.
- The pilot was very familiar with the aerodrome.
- The maneuver performed consisted of a series of snap rolls.
- This maneuver is performed by making inputs almost exclusively to the rudders; that is, by fully depressing the rudder pedal on the side to which the aircraft is to be rolled.
- To exit from the maneuver, the rudder pedal opposite to that used to start the turn is fully depressed.
- The AMT was in the habit of observing the pilot's maneuvers.
- The AMT warned the pilot to recover from the maneuver at the start of the 4th turn.
- The aircraft continued turning until it finally impacted the ground.
- An analysis of the wreckage showed that the aircraft had recovered from the maneuver and was not turning at the time of impact.
- No evidence was found in the aircraft wreckage of a mechanical, structural or engine failure.
- There are accounts involving the same aircraft type that detail how a pilot's foot can become stuck in some part of the pedal assembly or in the tubular structure that envelops the cockpit.
- The flight path observed by the eyewitnesses, and in particular by the AMT, who was used to watching these types of maneuvers, did not reveal any abnormalities.

3.2. Causes

The accident is believed to have been caused by:

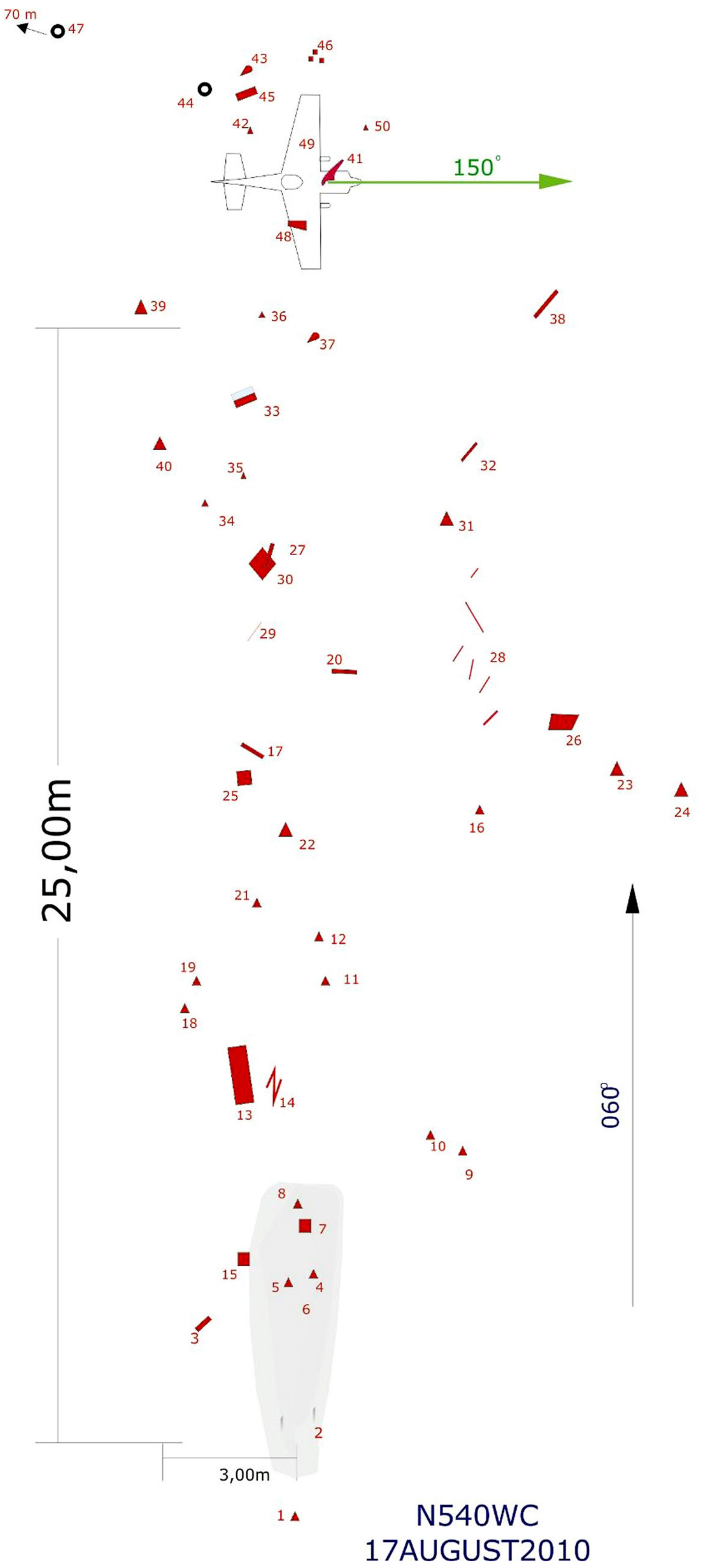
- An improper estimate of the starting altitude for a descending snap roll maneuver below that required to ensure the number of rolls the pilot wished to execute,
- A loss of consciousness that momentarily incapacitated the pilot, preventing him from exiting the maneuver in time or by
- The presence of a physical or mechanical obstacle or impediment, possibly involving the use of the pedals, that restricted or prevented the pilot from controlling the aircraft.

4. SAFETY RECOMMENDATIONS

None.

APPENDICES

APPENDIX 1
Layout of the debris field



1. Botton part of rudder
2. Wheel marks
3. spade support bar dug into ground
4. ADF antenna
5. Horizontal stabilizer counterweights
6. 6 m impact crater
7. Lower part of cockpit (methacrylate fragments)
8. Engine crankcase fragment
9. Fragment from lower leading edge of right wing
10. Angle of attack indicator
11. Right spade
12. Fuel inyector
13. Left lower side window
14. Tubular structure
15. Left spade
16. Starter
17. Control stick linkage
18 y 19. Methacrylate fragments from cockpit
20. Control stick
21. Propeller gear fragment
22. Carburetor throttle valve
23 y 24. Fairing fragments
25. Seat support
26. Engine cowl
27. Command bar intermediate bar
28 y 29. Propeller splinters
30. Seat cushion
31. Gascolator
32. Wing angle indication bar
33. Cockpit fragment
34 y 35. Battery fragments
36. Starting relay
37. Right wheel fairing
38. Propeller blade and spinner fragment
39. Cockpit fragment
40. Top part of rudder
41. Main fuel tank
42. Pitot
43. Left wheel fairing
44. Left wheel
45. Aft fuselage skin
46. EFIS and EDM
47. Right wheel (70m away)
48. Rudder
49. Main fuselage
50. Magneto