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Aircraft accident investigation bureau AAIB

Final Report No. 1909

by the Aircraft Accident

Investigation Bureau

concerning the accident

of the aircraft Pilatus PC-21, HB-HZB, Prototype P02

on 13 January 2005

on Buochs aerodrome, municipality of Buochs NW

approx. 12 km SSE of Lucerne

Bundeshaus Nord, CH-3003 Berne

GENERAL INFORMATION REGARDING THIS REPORT

This report contains the conclusions of the AAIB concerning the circumstances and causes of the investigated accident/serious incident.

In accordance with the Convention on International Civil Aviation (ICAO Annexe 13), the sole purpose of the investigation of an aircraft accident or serious incident is to prevent future accidents or serious incidents. The legal assessment of accident/incident causes and circumstances is expressly no concern of the accident investigation. It is therefore not the purpose of this investigation to determine blame or clarify questions of liability.

If this report is used for purposes other than accident prevention, due consideration shall be given to this circumstance.

The definitive version of this report is the original in the German language.

All times in this report, unless otherwise indicated, are indicated in local time (LT) for Switzerland, corresponding at the time of the accident to Central European Time (CET). The relationship between LT, CET and universal time coordinated (UTC) is as follows: LT = CET = UTC + 1 h.

The masculine form is used in this report regardless of gender for reasons of data protection

Contents

Final Report

Owner	Pilatus Flugzeugwerke AG, 6371 Stans
Operator	Pilatus Flugzeugwerke AG, 6371 Stans
Aircraft type	Pilatus PC-21 prototype
Country of manufacture	Switzerland
Registration	HB-HZB
Location	Buochs aerodrome
Date and time	13 January 2005, 16:39

General

Synopsis

On Thursday, 13 January 2005, a training flight was carried out which was intended to serve as preparation for a planned display of the two Pilatus PC-21 prototypes abroad. An aerobatics programme was to be practised during this flight.

In order to facilitate understanding, since two aircraft of the same type were involved in this flight, in the following report serial number P01 is used for aircraft HB-HZA and serial number P02 for aircraft HB-HZB.

The two Pilatus PC-21 aircraft took off in formation, in an easterly direction, from runway 07 L at Buochs at about 16:33. During take-off, the matt black aircraft P01 was flying in front as leader and the silver P02 followed as "wing man". After take-off, both aircraft climbed to approximately 5000 ft QFE (height above aerodrome). They then performed a steep dive and a low pass over the runway in a westerly direction, at low altitude and high speed. There followed a tight 180-degree turn over Stans. The formation then again performed a low pass over runway 07L. After an inclined 360-degree turn to the right, with a maximum height of 2200 ft QFE, the formation split over the centre line of the runway at a height of approximately 400 ft QFE. Aircraft P01 performed a loop over the runway centre line, and at the same time aircraft P02 flew a tight 360-degree turn at low altitude to the right. Towards the end of the 360-degree turn, aircraft P02 went into a shallow dive. A little later, its right wing clipped the ground. In the high-speed crash the aircraft was destroyed and a fire broke out. The pilot suffered fatal injuries. A passer-by was seriously injured in connection with the accident.

Investigation

The accident occurred on 13 January 2005 at 16:39. The notification was received at the Aircraft Accident Investigation Bureau (AAIB) at 16:55. The investigation was opened in co-operation with the Nidwalden cantonal police at the site of the accident on the same day at 18:00.

1 Factual information

1.1 History of flight

1.1.1 Pre-flight history

The Pilatus PC-21 aircraft had been developed by Pilatus Flugzeugwerke AG in Stans as a training aircraft for prospective military jet pilots. Two aircraft were built as prototypes and used for trials and for carrying out test flights and certification flights. The type certificate was issued in December 2004 for the Pilatus PC-21. However, the two aircraft with the serial numbers P01 and P02 were still prototypes and did not fully conform to the type certificate.

In addition to flight testing, these two aircraft were also used in displays for potential customers. In this context, participation at events abroad was planned, where the same aerobatics programme which had been presented by the same pilots at the Air 04 air show in Payerne in September 2004 was to be flown.

The departure of the two aircraft abroad was scheduled for Friday 14 January 2005. In preparation for the displays a further joint training exercise was to take place on Thursday 13 January 2005. A maintenance check and cleaning of the aircraft were scheduled beforehand.

This maintenance on both aircraft was carried out in the morning. Since, in addition to the check, various deficiencies had to be rectified, there was a delay. The pilot of aircraft P02 made use of the time for a discussion with his colleagues in connection with the management duties he had to perform in his department.

The customary briefing on the status of the aircraft and configuration by a member of the "Flighttest (EA)" department was not possible until after 15:30. At this time, both pilots were busy briefing the flight. Both had a copy of the planned programme in front of them. Whilst the pilot of P01 was studying the sequence, the pilot of P02 was informed of the work which had been performed on his aircraft.

During the briefing, it was decided that P01 would start as leader and a minimum height above ground of 500 ft was decided. Runway 07L/25R served as the centre line of the display and the road which crossed the aerodrome served as the '*centre*' (the centre of the display space). For the combined aerobatic figure looping and horizontal circle they convened, that P01 would fly along the axis of the runway and P02 remain south of the runway edge.

Once the briefing had ended, the pilots stated that they were satisfied with the status of the aircraft and were waiting to take over the aircraft.

At 16:15, the pilot of P02 again called the member of department EA in order to ascertain the availability of his aircraft, as the pilot of aircraft P01 was already on board. He was informed that the workshop was in the process of making the aircraft available. Around 16:25, the pilot climbed on board the aircraft in the hangar. Shortly after this, the maintenance was completed and P02 was rolled out of the hangar.

1.1.2 History of flight

After the formation had received clearance from the Buochs air traffic controller, both aircraft taxied to the holding point for runway 07L. The two Pilatus PC-21 aircraft took off in formation, in an easterly direction, from runway 07L at Buochs at about 16:33. During take-off, the matt black aircraft P01 was flying in front as "leader" and the silver P02 followed as "wing man". After take-off, both aircraft climbed to approximately 5000 ft QFE (height above aerodrome). They then performed a steep descent and a low pass over runway in a westerly direction, at low altitude and at high speed. There followed a tight 180 degree turn over Stans. The formation then again performed a low pass over runway 07L. After an inclined 360 degree turn to the right, with a maximum height of 2200 ft QFE, the formation split over the centre line of the runway at a height of approximately 430 ft QFE.

The separation took place 6 minutes and 12 seconds after releasing the brakes for take-off and the corresponding command was given by the pilot of aircraft P01 with the words "looping, looping now". When his aircraft passed the top of the loop after 14 seconds, the pilot confirmed that he had established visual contact with the other aircraft with the word "contact".

Three seconds later, when aircraft P02 had flown approximately 210° of its 360 degree turn, its pilot also confirmed that he had the aircraft in the loop in sight with the word "visual".

After a further ten seconds he asked the pilot of aircraft P01 to continue flying his figure with the words "keep going". His position was markedly behind that of aircraft P01.

Two seconds later, the pilot of P02 commented on the beginning of the next planned figure, a tight 180 degree turns, with the words "turn right".

After another eight seconds, the pilot of aircraft P01 asked "where are you?", as he was expecting aircraft P02 to catch up with him but did not have the latter in sight.

One second later, the ground observer of the exercise informed him "we have an accident".

According to eye-witness statements, aircraft P02 went into a shallow dive towards the end of the 360 degree turn. A little later, its right wing clipped the ground. In the high-speed crash, the aircraft was destroyed and a fire broke out. The pilot suffered fatal injuries.

A passer-by was seriously injured.

Aircraft P01 was able to land on Buochs aerodrome undamaged.

1.2 Injuries to persons

	Crew	Passengers	Third parties
Fatally injured	1	---	---
Seriously injured	---	---	1
Slightly injured or uninjured	---	---	

1.3 Damage to aircraft

The aircraft was destroyed.

1.4 Other damage

As a result of the shallow impact of the aircraft on the frozen ground between the two runways there was only slight damage to the terrain in this area. However, there was slight contamination of the soil due to leaking fuel.

The aircraft's impact on the protective embankment of the Engelberger Aa river caused damage to the embankment and the surrounding vegetation. The fuel which leaked out was largely consumed by the fire.

In addition, there was slight contamination of the Engelberger Aa river. This contamination was combated by the competent military services.

1.5 Personnel information

1.5.1 Pilot P02

Person	Swiss citizen, born 1965
Licences	Air Transport Pilot's Licence, issued by the Federal Office for Civil Aviation on 29.11.2004 Commercial Pilot's Licence, helicopter CPL(H)
Ratings	RTI (VFR/IFR); NIT (A); IFR (A); CRI (A); ACR (A)
Registered aircraft classes	SE Piston; Pilatus SET
Registered aircraft types	PC12; PC9/PC7MkII
Medical fitness certificate	Class 1 VDL (must wear spectacles)
Last medical examination	13 August 2004
Other permissions	Special permission A for performing aerobatics below the legal minimum height above ground issued by the Federal Office for Civil Aviation on 02.08.2004

Flown hours	Total aircraft:	8480 hours
	During the last 90 days:	85 hours
	PC-21:	411 hours
	PC-21 during the last 90 days:	48 hours
Number of flights on PC-21	374 during the last 90 days:	45

1.5.1.1 Experience

The pilot concluded his flight training in civil aviation.

Before joining Pilatus Flugzeugwerke AG, he had flown twin-jet business jets and commercial turboprop aircraft.

The FOCA issued him an aerobatics rating in 1991. In 2001, the pilot had attended a course for test pilots of several weeks' duration at the National Test Pilot School (NTPS) in the USA. According to the available documentation, no training in aerobatics or formation flying was provided at this school. All further training in aerobatics took place within the company.

On 16.11.2000, the pilot was authorised after an internal check to perform aerobatics down to a minimum height of 500 ft; the training took place on a PC-9. The first flight training on a PC-21 in formation flying and low flying took place on 26.08.2004. Up to the end of the year, a further 8 training units were flown under the supervision of a works pilot.

During the two weeks before the accident, he had carried out several aerobatic flights.

The aerobatics programme which was flown on the day of the accident had already been practised earlier by the two pilots on Buochs aerodrome.

1.5.1.2 Other duties

In addition to his activity as a works pilot with Pilatus Flugzeugwerke AG, the pilot involved in the accident of aircraft P02 had been designated Chief Test Pilot and Manager Flight Operations in 2002. In addition to his activity as test pilot and works pilot, he was therefore also responsible for the management of this entire unit. This also involved a large amount of organisational work.

In addition to the test flights and certification flights, he carried out many works flights for the production of the Pilatus PC-12 aircraft. Moreover, the forthcoming trips had to be organised and as many as possible of the foreseeable tasks had to be dealt with before his absence.

1.5.2 Pilot P01

Person	Swiss and British citizen, born 1942
Licence	Commercial Pilot's Licence CPL (A), issued by the Federal Office for Civil Aviation on 05.07.2004
Ratings	RTI (VFR/IFR); NIT (A); IFR (A); ACR (A)
Registered aircraft classes	Pilatus SET
Registered aircraft types	PC12; PC9/PC7MkII
Medical fitness certificate	Class 1
Last medical examination	25 October 2004
Other permissions	Special permission A for performing aerobatics below the legal minimum height above ground issued by the Federal Office for Civil Aviation on 02.08.2004
Flown hours	Total aircraft: 9152 hours
	During the last 90 days: 44 hours
	PC-21: 354 hours
	PC-21 during the last 90 days: 37 hours
Number of flights on PC-21	301 during the last 90 days: 35

1.5.2.1 Experience

The pilot was trained in aerobatics and formation flying within the framework of the military regulations and worked as a jet pilot for a foreign air force.

The FOCA issued him with a civil rating for aerobatics in 1982.

During his activity as a works pilot and test pilot for Pilatus, he transferred his specialist knowledge of aerobatics and trained pilots in this discipline.

1.5.3 Passer-by

Swiss citizen, born 1977

A footpath is situated on the embankment on the north side of the Engelberger Aa. A passer-by was walking with his dog on this path towards Stans. When the wreckage impacted the embankment, the fuel ignited. The resulting heat and flame front engulfed the passer-by. He was thrown into the Engelberger Aa by the pressure wave and was seriously injured in the process.

1.6 Aircraft information

The two aircraft had been used as prototypes in the certification process and did not completely correspond to the type certificate which had been issued since then. The aerodynamic configuration of both aircraft was identical.

1.6.1 General

Manufacturer	Pilatus Flugzeugwerke AG
Type	PC-21 prototype
Characteristics	Turboprop aircraft, low-wing, full metal construction with pressurised cabin and ejector seat
Seating positions	Tandem arrangement with raised rear seat; minimum crew: one pilot in the front seat
Year of construction / serial number	2004 / P02
Airworthiness certificate	Provisional airworthiness certificate, issued by the Federal Office for Civil Aviation on 02.06.04/No. 1 valid till 31.05.05. Valid for flights within the framework of the approved flight testing programme. Validity in non-commercial transport. Special category Experimental (prototype).
Certification	VFR day
Operating hours	161:17 hours
Mass and centre of gravity	The applicable masses are specified in the AFM as follows: Basic empty mass: 2340 kg Maximum ramp mass: 3120 kg Maximum take off mass: 3100 kg Maximum landing mass: 3100 kg Maximum zero fuel mass: 2750 kg Maximum mass in bag. compartm.: 25 kg The take-off mass of the aircraft was 2822 kg. The mass and centre of gravity were within the permitted limits.
Maintenance	On 12.01.2005, at 161:17 operating hours, an early 100 hour inspection was carried out. WO No. 819742.
Fuel	462 litres JET A1 fuel on board according to the load sheet. In view of the degree of destruction and because of the fire, no fuel was available for an investigation.
Flight time remaining	Approximately one hour for the flight at low altitude and high power.

1.6.2 Engine

1.6.2.1 General

Manufacturer	Pratt and Whitney Canada
Type	PT6A-68B
Serial number	S/N 1712
Construction	Free turbine turboprop
Year of construction	2003
- Operating time since manufacture	269:37 h
- Flying cycles since manufacture	336 cycles

1.6.2.2 Power management system (PMS)

The PMS regulates the maximum engine power as a function of speed (power scheduling). During the initial take-off roll, reduced engine power only is available (805 kW or 1080 SHP); this is then increased progressively as speed increases (above 200 kt to 1193 kW or 1600 SHP).

As a result, among other things the behaviour of the aircraft on take-off and acceleration is intended to resemble that of a jet aircraft.

1.6.3 Propeller

Manufacturer	Hartzell
Type	HC-E5A-2/E9193B,K
Construction	5-bladed, variable pitch, feathering, constant speed composite propeller

1.6.4 Cockpit equipment

1.6.4.1 General

The PC-21 aircraft has a modern two-man glass cockpit in a tandem arrangement. The equipment consists of IFR equipment with FMS according to civil criteria and a military mission computer with the corresponding displays.

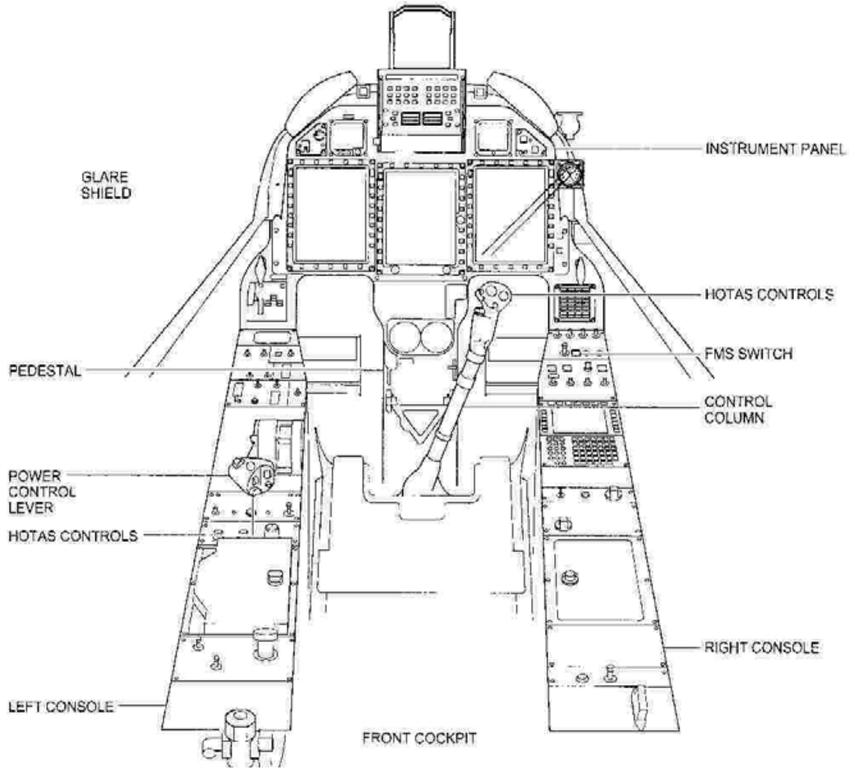
View of the PC-21 P02 tandem cockpit

1.6.4.2 Cockpit layout, front seat

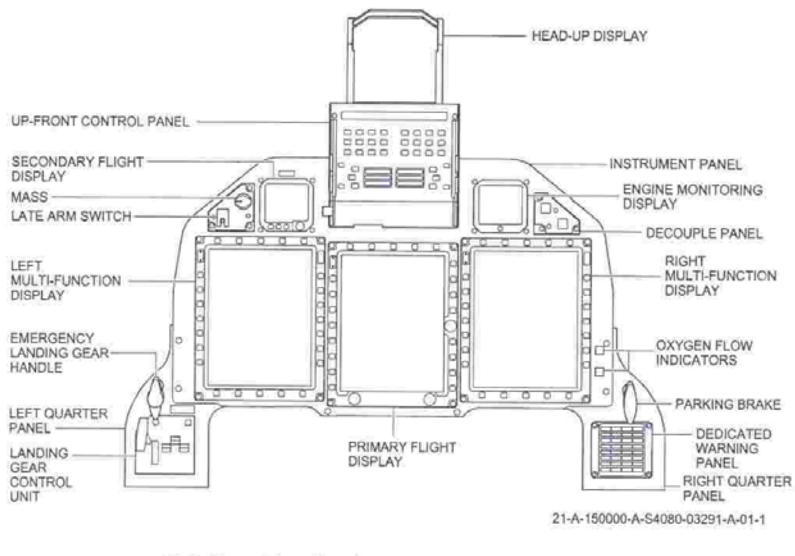
The controls and displays at the front are located in a main instrument panel, a glare shield panel, on the left and on the right a side console and a pedestal. Control is exercised via so-called HOTAS (Hands On Throttle And Stick) controls on the power control lever (PCL) and on the control column.

The main elements of the instrumentation are:

- head-up display (HUD)
- up front control panel (UFCP)
- engine monitor display
- primary flight display (PFD)
- 2 multi function displays (MFD)
- AMLCD standby instruments



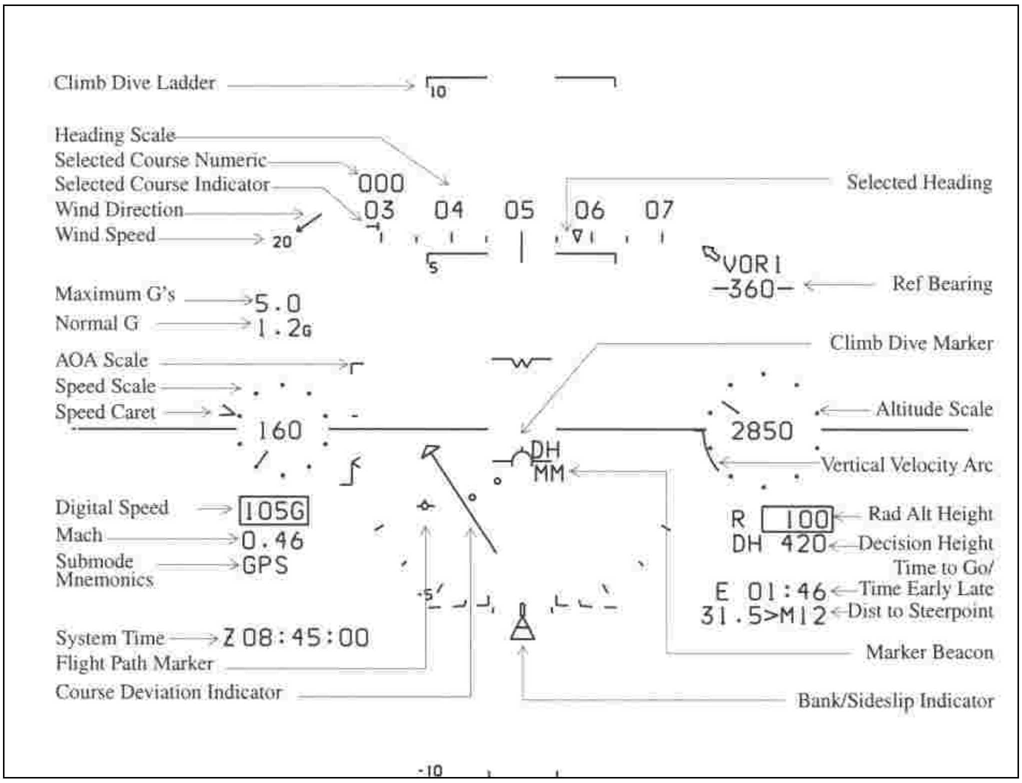
Layout of the front workstation



Layout of the instrument panel

1.6.4.3 Head-up display (HUD)

The cockpit was equipped at the front with a head-up display. The most important flight data were projected in the pilot's primary field of view, so that they were visible to the pilot at all times.



Sample of the head-up display information visible in the field of view

1.6.4.4 Altimeter

The PC-21 is equipped with two different altimeter systems:

- a barometric altimeter system
- a radio altimeter system

1.6.4.4.1 Barometric altimeter system consisting of the following components

- pitot static system
- primary air data computer ADC
- secondary air data unit ADU

The pitot static system (*Prandtl*) supplies the necessary parameters, i.e. static and total pressure, to the primary air data computer (ADC). This supplies the altitude data to the following devices:

- altimeter displays
- PFD
- FMS
- HUD signal generator -HSG

The ADC converts the pressure signals into engineering units and makes the information available on the ARINC Bus.

The secondary air data unit (ADU) is a dumb box, which merely converts the pressure signals into raw digital signals. These signals are only converted into so-called engineering units in the secondary flight display (SFD) for display purposes.

Altimetry errors

Measurement errors occur in all aeronautical barometric altimetry systems. Among other things, these depend on airspeed, altitude and aircraft configuration. This error is particularly great at high airspeeds.

The ADC processor could be fitted with a static source error correction (SSEC) chip, in order to correct the measurement errors found during the licensing flights.

P02, the aircraft involved in the accident, was equipped with an SSEC chip. At approximately 300 kt at aerodrome altitude, the corrected measurement error was 30 ft +/- 15 ft.

Aircraft P01 was not equipped with an SSEC chip.

In the case of aircraft P01 without an SSEC chip, the altimetry error at approximately 300 kt at aerodrome altitude was 120 ft +/- 15 ft, i.e. the displayed value was approximately 120 ft lower than the actual altitude.

1.6.4.4.2 Radio altimeter system consisting of the following components

- radar altimeter transceiver
- transmit antenna
- receive antenna

The radar altimeter transceiver (TXCVR) sends a signal to the ground via the transmit antenna. The signal reflected from the ground is received by the receive antenna and forwarded by it to the TXCVR. The receiver calculates the altitude and transfers the data via the ARINC 429 Bus to the open system mission computer, the HSG and the front and rear PDF.

If the aircraft flies below the set decision height (DH), a signal is transmitted from the front PFD to the audio management unit AMU.

1.6.4.4.3 Utilisation of the displayed barometric altitude in the P01 HUD

From the HUD camera video recording it was possible to establish the barometric altitude displays on the HUD during the entire flight of P01. The altitude data were based on the QFE setting before the flight and indicated the height above Buochs aerodrome.

For all the P01 altitude information entered in the report, the values taken were those which had been displayed on the HUD, i.e. no account was taken of the SSEC.

1.6.5 System description, flight control

1.6.5.1 Primary control

The aircraft was controlled by three independent systems.

- By aileron and spoiler around the longitudinal axis (roll control)
- By elevator around the transverse axis (pitch control)
- by rudder around the vertical axis (yaw control)

Elevators and rudder were linked by cables and rods.

The ailerons were linked by rods. Deflection of the two ailerons was supported hydraulically by a servo-actuator.

To increase the speed of rotation about the longitudinal axis, two hydraulically actuated spoilers, left and right, were mounted on the top of the wing close to the two ailerons. They were lifted, starting at an aileron deflection of 4° up and achieved their full extension at an aileron deflection of 14°.

All the above controls were provided with electric trimming.

The aircraft was equipped with dual controls.

1.6.5.2 Secondary control

The secondary control system consisted of flaps and an airbrake, which were operated hydraulically.

1.6.6 Ejector seat

1.6.6.1 General

Two Martin Baker (MB) Type A Mk CH16C ejector seats were installed in aircraft P02. This type was a lightweight seat for turboprop military training aircraft. Up to the time of the accident flight, four such seats out of a planned first series of 12 seats had been built.

1.6.6.2 Operating limits

The Type A Mk CH16C ejector seat was specified as a so-called 0/0 seat, meaning that successful ejection was guaranteed at a speed of 0 kt and a height of 0 ft above ground.

The minimum height above ground for a safe ejection close to the ground depended on the following parameters:

- speed of the aircraft
- bank angle
- rate of descent
- attitude

The required minimum heights for successful ejection close to the ground were laid down for the individual flight conditions in a total of 21 tables.

More details on these operating limits are provided in section 1.15 with regard to the flight involved in the accident.

1.6.7 Pressurised cabin and equipment for the anti-g suit

The PC-21 was the first model in the range of Pilatus trainers to be equipped with a pressurised cabin. Pressure generation and regulation were handled by a so-called cabin conditioning system, which also supplied the pressurisation of the anti-g system. It was mandatory to wear an anti-g suit on every flight and to connect it to the system.

During the flight involved in the accident, the pilot was equipped with an anti-g suit. The damage to the connecting hose of the anti-g suit indicated that the latter was connected to the system.

There were no indications, and in particular no statements by the pilot, that the anti-g suit was not functioning.

1.6.8 Finish of the aircraft P01 and P02

Aircraft P01 was painted matt black (Akzo Aerodex Finish matt 00744 black).

Aircraft P02, the one involved in the accident, was painted silver-grey (Akzo ECL-G-850 Mica Silver non-metallic System plus ECL-G-2 Clearcoat).

1.6.9 Maintenance of the aircraft

The aircraft were maintained by the Experimental Shop (AX), a specialised unit of Pilatus Flugzeugwerke AG.

Periodic checks carried out on aircraft P02:

Date		Airframe hours (time since new)
12.01.2005	100 + 50 + 25 hour check	161.17 hours
03.12.2004	25 + 50 hour check	143.48 hours
05.10.2004	25 hour check	115.57 hours
13.09.2004	100 + 50 + 25 hour check	92.31 hours
27.08.2004	25 hour check	73.10 hours
07.08.2004	25 + 50 hour check	50.31 hours
09.07.2004	25 hour check	25.33 hours

In addition to the periodic checks, deficiencies were rectified on an ongoing basis and modifications and tests arranged by the Flight Test Department were implemented. Proper documentation was maintained for all this work.

No airworthiness directives were published, so none were applicable.

The investigation revealed that the ejector seats had been removed and refitted to gain access to various components. No specific record was kept of these removals and refittings.

1.7 Meteorological information

1.7.1 General weather situation

A weakened cold front had crossed Switzerland in the course of the day in a north-westerly upper air current. A high-pressure area centred over France was increasingly affecting the weather in Switzerland.

1.7.2 Weather at the time and location of the accident

The following information on the weather at the time and location of the accident is based on a spatial and chronological interpolation of the observations of different weather stations. This interpolation was done by MeteoSchweiz.

Cloud	3-4/8 at 6000 ft AMSL
Visibility	about 10 km
Wind	Variable at 1 – 3 kt
Temperature/dew point	05 °C / 02 °C
Atmospheric pressure	QFE 977 hPa; QNH 1030 hPa
Dangers	None detectable

1.7.3 Weather according to witness statements

A witness described the weather as very good, with visibility in excess of 20 km. Broken cloud cover of about 4/8 was located at 6000 to 7000 ft AMSL in the vicinity of the Buochserhorn. At this time of day, the clouds appeared very bright in comparison with the terrain as a result of the low position of the sun.

1.7.4 Position of the sun and lighting in relation to Buochs aerodrome

1.7.4.1 Astronomical data for 13.1.2005 (local time)

Sunrise	08:09
Sundown	17:02
End of civil twilight	17:36
Moonrise	10:26
Moonset	20:57
Moon phase	0.15 (waxing)

Remarks:

The time for civil twilight differs from that published in the AIP (17:40) because the last one refers to Bern.

Also sunrise and sundown may not be compared with those from the AIP, because different definitions are used.

1.7.4.2 Position of the sun

At the time of the accident, the sun was low on the south-west horizon. The azimuth was 235° and the elevation was 2.6°.

The diameter of the sun was 32.5 arc minutes (approximately 0.5 degrees).

1.7.4.3 Shadow on the terrain

The shadow cast onto the ground was calculated by the Swiss Federal Office for Topography for a 2.6 degree elevation of the sun. It must be borne in mind that at such a low angle of incidence any inaccuracies in the elevation model (DHM25) are magnified accordingly.

The model shows large parts of the landscape in shadow, including the entire southern part of the aerodrome with the runway. Bürgenstock and the south-west side of the Rigi were still in sunlight. Please refer to appendix 3.

1.7.4.4 Clouds

At 2.6 degrees elevation of the sun, even light clouds have a major effect. Video recordings made by the camera of the accompanying aircraft show the clouds and the aerodrome completely in shadow.

1.8 Aids to navigation

Not involved.

1.9 Communication

The formation was in radio contact with the Buochs air traffic controller (Buochs TWR). This radio communication took place on the aerodrome frequency of 119.625 MHz and was handled by the pilot of aircraft P01.

The pilot of P01 requested taxi clearance after the engines had been started and received it During his taxi, hw informed the air traffic controller about the planned programm. After line-up on runway 07L, the air traffic controller issued the take-off clearance.

When the formation was ready to begin their training, they reported overhead Gersau at 5000 ft. The air traffic controller authorized it as follows:

"…aerobatics aooroved, wind calm"

There was no further radio contact between the air traffic controller and the formation.

Communication between the two aircraft P01 and P02 took place on the company frequency. The ground observer also communicated with the pilots on this frequency.

Find bellow the transcription of the radio communications from the beginning of the loop up to the time of the accident.

Time in minutes and seconds since:					
Switching on the main switch	Releasing brakes during take-off	order "looping, looping now"	Text	by	Position of the aircraft
21:09	06:12	0:00	*looping, looping now*	P01 pilot	
21:14	06:17	0:05	*nice*	Observer	
21:23	06:26	0:14	*contact*	P01 pilot	Top of the loop
21:26	06:29	0:17	*visual*	P02 pilot	after approximately 210° of the 360° turn
21:36	06:39	0:27	*keep going*	P02 pilot	
21:38	06:41	0:29	*turn right*	P02 pilot	
21:46	06:49	0:37	*where are you*	P01 pilot	
21:47	06:50	0:38	*we have an accident*	Observer	

1.10 Aerodrome information

Buochs aerodrome, ICAO code LSZC, was an aerodrome for combined military and civil use. The airport reference point (ARP) was N 46°58 28' and E 008°23 49 (WGS 84) or 672 910/202 990 (Swiss Grid) 2 km to the west of Buochs. The reference elevation was 1473 ft or 449 m AMSL.

The hard runway 07L/25R was 2000 m long and 40 m wide. Its magnetic orientation was 064° or 244° respectively, with a variation of 0°39'E.

The so-called "emergency runway"07R/25L run parallel 300 m to the south; it was 1500 m long and 40 m wide. This was also a hard runway.

The aerodrome could be used as well during its hours of operation, when it had an aerodrome traffic control unit as outside these times. Prior permission is required at all times (PPR: prior permission required).

The aerodrome was used by the Pilatus Flugzeugwerke AG company as a company aerodrome. The aerodrome could be reached from the factory area via a taxiway. This crossed a public road. The taxiway/road crossing was provided with a radio-operated signalling system.

During military flying operations, a Class D control zone was active from the ground up to flight level 130.

1.11 Flight recorders

1.11.1 General

1.11.1.1 Installation regulations for flight data recorders in Switzerland

The installation of a flight data recorder was not prescribed for this aircraft.

1.11.1.2 Flight recorders in the PC-21

A mission data recorder system and a flight test instrumentation system were normally installed in the two aircraft, P01 and P02.

However, all the flight test instrumentation equipment had been removed from both aircraft for the display abroad.

1.11.1.3 Brief description of the mission data recorder

The mission data recorder is based on a computer with a Windows XP operating system and has the following functions:

- Recording data from the open systems mission computer, plus 2 video channels and 2 audio channels on the removable memory module, a solid-state NTSF formatted disk.
- During flight preparation, data for the flight can be saved to the removable memory module (brick) on the ground via a PC; in flight, these data are then accessed by the open system mission computer. Conversely, flight data is recorded using the open system mission computer and analysed subsequently on the ground.
- The data processed by the open system mission computer are transferred via an Ethernet link to the mission data recorder. Video and audio signals are fed via separate inputs.

- The Windows XP operating system and application software were stored in the permanent memory module on the PCMCIA flash storage card.

1.11.1.4 Brief description of the flight test instrumentation

A flight test instrumentation system was installed in the luggage space behind the cockpit as additional equipment for carrying out the certification flights. This consisted of data capture, telemetry, recording and sensors.

256 different signals could be conditioned and recorded. The majority of the signals originated from strain gauges which were fitted to many relevant points in the aircraft. In addition, system data were also recorded.

The data were transferred via the built-in radiotelemetry system to the ground station and simultaneously to a solid-state data recorder with a capacity of 3.26 gigabytes. Consequently, the data was backed up in the aircraft in the event of an interruption in the telemetry.

The telemetry system operated in the VHF range. The 4 antennae on the aircraft, arranged uniformly on the circumference of the fuselage, were fed from a 15 watt FM transmitter.

1.11.1.5 Mission data recorder in P02, the aircraft involved in the accident

The mission data recorder was installed in the aircraft. Since no removable memory module was installed, no recordings could be made. Hence no flight parameters were available to the investigation for analysis.

In view of the minor damage to the mission data recorder and other electronic devices in the cockpit area, it can be assumed that any recorded flight parameters would have been readable.

1.11.1.6 Mission data recorder in P01, the sister aircraft

The mission data recorder was installed in the aircraft. A removable memory module was fitted and in operation. According to information from Pilatuswerke AG the data feed via Ethernet was not working. Consequently no flight parameters were recorded in the removable memory module. However, the removable memory module had recorded the video signal from the on-board camera and the audio signal from the audio management unit, as these two signals had a separate input. It was possible to analyse the video and audio recordings.

1.11.2 Analysis of the P01 video recordings

1.11.2.1 Introduction

Aircraft P01 and P02 were equipped with a permanently installed camera positioned in front of the HUD. The camera recorded a forward view of the area in front of the aircraft. The symbols of the HUD were electronically superimposed onto the video signal. The mission data recorder was able to record this signal.

No removable memory module was installed in P02, the aircraft involved in the accident, so no recording was available. However, it was possible to analyse the video data from the sister aircraft P01 which enabled reconstruction of the loop by P01 prior to the accident.

For the analysis, the data were divided into two sub-areas:

- Data which was based only on the HUD displays and which were therefore independent of the video signal provided by the camera.
- Data which additionally included the area visible on video, the analysis of which was therefore dependent on the characteristics of the camera and its installation. Here greater deviations than normal had to be taken into account as a result of the tolerances of the camera alignment and the superimposition of the HUD symbols.

In order to evaluate the accuracy of the video data used, these were first compared with an earlier flight by P02, during which the flight data has been recorded. The comparison showed that this method provides sufficiently accurate results. It should be noted that the video recordings provided 30 datasets per second, whereas the mission data recorder provided only one dataset per second.

1.11.2.2 Camera installation

Since the aircraft was equipped with an HUD for the pilot in the front cockpit seat only, a representation on a video monitor was provided for the pilot in the rear cockpit seat. This showed a video image of the forward view, with the HUD information superimposed on it.

The digital video camera was fitted with a lens with a focal length of 16 mm. The camera was fitted in front of and slightly below the HUD with a longitudinal inclination of minus 3° in relation to the longitudinal axis of the aircraft.

Since various uncertainties existed with regard to the recorded field of view, this was determined during the investigation through a test. The horizontal field of view was 21.8° and the vertical field of view was 15.5°.

1.11.2.3 Camera adjustment

For the HUD and video displays to be aligned with the longitudinal axis of the aircraft, they had to be adjusted. This took place in two stages:

1. The HUD symbols were adjusted according to the longitudinal axis of the aircraft.
2. The camera image was centred on the longitudinal axis of the aircraft and the HUD display.

Some time after the accident, the HUD symbol generator, in which the adjustments were also stored, had to be swapped out on aircraft P01. After that the HUD symbols and video were re-set.

By means of the above-mentioned test and the available video data, the adjustment at the time of the accident could be reconstructed with reasonable accuracy. The optical axis was inclined approximately 3° downward in relation to the longitudinal axis of the aircraft (which corresponded to the mechanical installation) and offset approximately 1.8° to the right. These values were in accordance with the observations of the video from take-off and approach.

1.11.2.4 Results of the HUD data analysis

General: Only the HUD symbols on the video were used for the HUD data analysis, i.e. without reference to the terrain. This meant that the data were correct within the accuracy of the system and the read-out.

Pitch: in the first quarter of the loop the pitch rate was constant. Thereafter, it exhibited certain variations and a reduction towards the end of the loop.

Bank angle: the roll angle in the loop was around zero up to the last quarter, when the bank angle was 10°-28° to the right.

Heading: the heading increased in the first quarter of the loop from approximately 64° (runway direction) to approximately 70°. In the last quarter of the loop, the heading changed continuously from 56° to 86° and was therefore never stable.

In inverted flight, the heading could not be clearly determined, because only the gradations were recorded on the video, not the values. For the first quarter of the loop, the runway markers served as a reference, and for the last quarter the passing zero marker on the HUD symbols was used.

Barometric altitude (BAROALT): the altimeter was set to QFE and therefore showed the height above the aerodrome. The loop was started at 390 ft QFE and ended at 180 ft QFE; the height loss was therefore about 210 ft.

The top of the loop was at about 3680 ft QFE.

Radio altitude (RADALT): the radio altitude at the start of the loop was about 100 ft higher than the barometric altitude. At the end of the loop it was about 150 ft (this can be explained at least in part by the longitudinal inclination of the runway).

This discrepancy can hardly have been caused by the inertia of the BAROALT, because in this case the barometric altitude would be greater than the radio altitude.

A comparison with earlier data from P02 showed the same effect.

An analysis of data from different flights showed, that the discrepancy was attributable to the different aircraft configuration (gear and flaps retracted).

Normal acceleration:

Normal acceleration (N_z) could not be clearly determined for somewhat less than the first half of the loop. In the second half, the load twice briefly increased from 4 g to 5 g. Minimum acceleration at the top of the loop was +0.4 g.

1.11.2.5 Snapshots

With reference to the flight a data set for five specific moments had been recorded as follows:

At the moment of the radio communication: *"looping, looping now"*, the following data was extracted from the HUD of P01:

- Video time: 00:21:09
- Altitude: 430 ft Baro Alt
- Height: 741 ft Rad Alt
- IAS: 309 kt
- Heading: 062°

- N_z: 3.3 g
- Pitch: -5.8°
- Angle of Bank (AOB): 50° right

About one second later, when pitch and roll were zero, the data showed the following values:

- Video time: 00:21:10
- Altitude: 390 ft Baro Alt
- Height: 487 ft Rad Alt
- IAS: 308 kt
- Heading: 065°
- N_z: 3.6 g
- Pitch: 0°
- AOB: 0°

At the moment, when the aircraft P01 passed the planed minimum altitude of 500 ft and the communication "keep going" was heard, the following data was extracted from the HUD:

- Video time: 00:21:36
- Altitude: 500 ft Baro Alt
- Height: 689 ft Rad Alt
- IAS: 300 kt
- Heading: 070°
- N_z: 3.0 g
- Pitch: -20°
- AOB: 20° right

At the moment of the radio communication: "*turn right*", the following data was extracted from the HUD of P01:

- Video time: 00:21:38
- Altitude: 270 ft Baro Alt
- Height: 430 ft Rad Alt
- IAS: 307 kt
- Heading: 077°
- N_z: 3.1 g
- Pitch: -10°
- AOB: 25° right

When the aircraft P01 reached his lowest height, the following data was extracted from the HUD:

- Video time: 00:21:39
- Altitude: 180 ft Baro Alt
- Height: 331 ft Rad Alt
- IAS: 308 kt
- N_z: 3.1 g
- Pitch: 0°
- AOB: 23° right

1.11.2.6 Flight path and development of a 3D- model

The flight path of P01 was reconstructed from various reference points visible in the video. As a base were used:

- Calculations from the video recordings of aircraft P01
- Orthophotos from the airfield and his environment
- Digital height model (DHM 25)
- 2D- plan of the airfield
- Data from the survey of the accident site

The flight path of P02 was reconstructed mathematically und verified based on data from earlier flights as well as statements from pilots and witnesses. The timing was adapted to the loop flown by P01. As starting point, the position as wingman in the formation was used and as end point the point of impact.

Both flight path were drawn tri dimensionally and fitted in the terrain model. The reconstructed flight path of P01 was the correlated with the video image best possible (see appendix 5).

The loop was started with some degree of certainty at the middle of the runway and slightly to the right of the runway centre line.

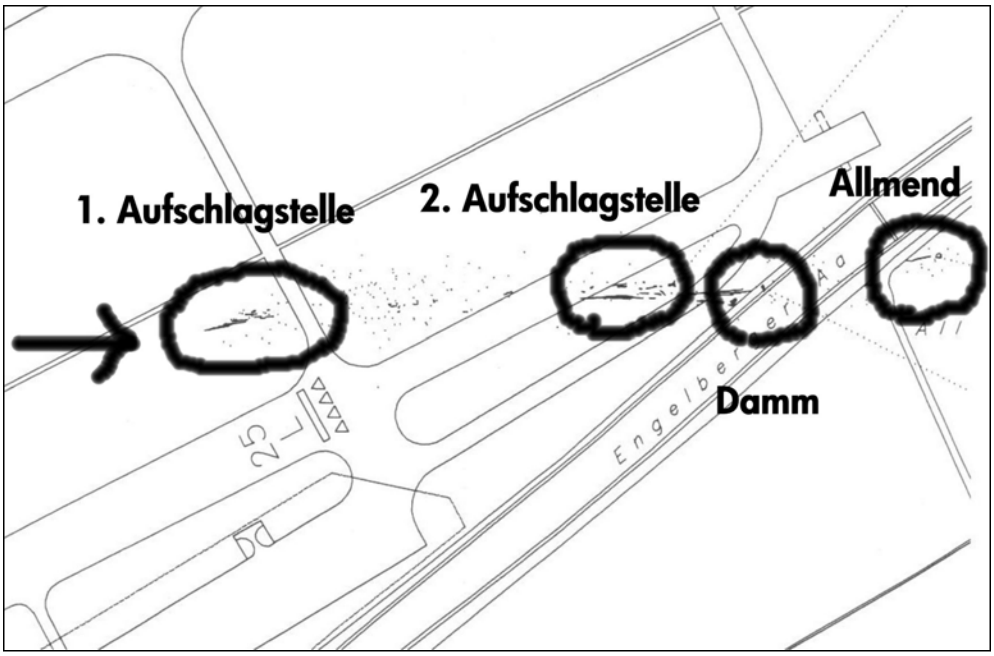
Approximately six seconds before the end of the loop the aircraft travelled over the runway centre line to the right. The distance in relation to the runway centre line increased to approximately 140 metres at the end of the loop.

The loop was completed approximately 600 m to 1000 m after the middle of the runway.

1.12 Wreckage and impact information

1.12.1 The site of the accident

Most of the site of the accident was located on Buochs aerodrome and extended from the area north of the threshold of runway 25L over the Engelberger Aa river as far as "*Buochser Allmend*". See also appendix 1. The area of damage was approximately 520 m long and 110 m wide.



1st point of impact 2nd point of impact Embankment "Allmend"

1.12.2 The impact

Immediately prior to the impact, the aircraft was flying at a bank angle to the right of approximately 30°-40° in a shallow dive. The aircraft touched the frozen, flat terrain of the aerodrome with the tip of its right wing. See the detailed simulation in appendix 4.

After rolling level, the aircraft slid across a taxiway and was catapulted into the air again. The cockpit canopy began to rupture during this phase. The distance to the second point of impact was approximately 160 m. During this flight phase, parts of the wing and fuselage separated. The tail was torn off during the second impact on the terrain of the aerodrome, between runway 25L and the Engelberger Aa embankment. The remainder of the aircraft slid along the ground and after about 75 m it hit the slope of the embankment side-on, with the front of the fuselage section pointing south. During this impact, the aircraft broke up into several sections which were scattered in different directions. In the process an intense fire broke out.

The wing separated from the fuselage and came to rest on the embankment. The pilot and the forward ejector seat, was found on the south-east bank of the Engelberger Aa river. The engine was thrown into the Engelberger Aa. The fuselage with the cockpit and the rear cockpit ejector seat were thrown approximately 150 m beyond the river onto "*Buochser Allmend*".

The distance from the initial contact point on the ground to the final position of the fuselage was 440 m.

Coordinates (Swiss Grid):

First point of impact	673 570 / 203 150
Second point of impact	673 740 / 203 160
Embankment point of impact	673 870 / 203 150
Common point of impact	674 010 / 203 170

Sheet No. 1171 Beckenried, National map of Switzerland 1:25 000

1.12.3 First findings relating to the parts of the wreckage

See also appendix 1 and 2.

1.12.3.1 First point of impact

The parts first detached from the wreckage were the tip of the right wing and the right aileron.

The badly shattered and detached propeller blades were lying in the environs of the point of impact.

Part of the engine oil cooler lay at the point at which the fuselage first impacted.

1.12.3.2 Area between the first and second point of impact

This area was covered with parts of the wreckage of the aircraft, which had broken up in the air. The most notable parts were:

- parts of the right aileron
- parts of the airbrake
- parts of the flap system

- parts of the leading edges of the left and right wings
- Plexiglas parts of the cockpit canopy
- pilot's helmet and the two separated visors

1.12.3.3 Second point of impact

The rear section of the fuselage which had separated from the aircraft lay at the end of the second point of impact. The rudder and the two elevators together with the corresponding trim tabs were secured to the rear section of the fuselage, with minimal traces of impact. From the parts found it was not possible to draw any conclusions concerning the rudder/elevator settings and trim before the impact.

1.12.3.4 Embankment point of impact

The very distinct point of impact on the western slope of the embankment of the Engelberger Aa river, the traces of fire found here and the main parts of the wreckage lying further to the east, such as the engine, wing and fuselage, allow the conclusion that final destruction of the aircraft with separation of the fuselage, engine and wing took place at this point. The degree of destruction of the main parts of the wreckage permits the conclusion that the aircraft impacted the slope of the embankment side-on, with the front part of the fuselage pointing to the south.

During this impact the two ejector seats were also thrown out of the cockpit.

The central section of the wing with the main gear, severely damaged, lay on the embankment of the Engelberger Aa river.

1.12.3.5 The Engelberger Aa

The front ejection seat lay on the south bank of the Engelberger Aa river and was badly damaged. The release handle had been torn out of its bracket. The pilot had been separated from the ejector seat belts and lay not far from the ejector seat. Part of the parachute had been pulled out of its pack.

The engine was also on the south bank in the Engelberger Aa.

1.12.3.6 The common

The fuselage and the rear ejector seat lay 175 m to the east of the embankment point of impact.

1.12.4 Identification and survey

The debris field was surveyed in detail. The parts of the wreckage were identified and logged accordingly. In addition to the photographic record, a new system was applied to survey the site of the accident. Further information on this can be found in section 1.19.

1.12.5 Examination of the parts of the wreckage

The wreck was examined after it had been recovered. In particular, the flight controls and the engine were subjected to comprehensive examination. Among other things, the following points were established:

1.12.5.1 Flight controls

It was possible to identify the wing and rudder surfaces, the control elements and the components of the landing flap system. A visual inspection of the control columns, rudder pedals, guide pulleys, control cables, turnbuckles and the components of the flap system produced no indication of any malfunction of the controls and flaps.

During the visual inspection of the wreck, no fractures which indicated pre-existing damage such as fatigue, corrosion or thermal effects could be found.

The parts examined in the laboratory were manufactured from materials which were typical and appropriate for aircraft applications. The microfractographic and macroscopic fracture analyses produced no indications that these parts were defective before the crash. They were all fractures which had been caused by the crash. In particular, no technical material defects could be found and there were no signs of primary damage due to fatigue, corrosion or thermal effects.

A comprehensive investigation was carried out to determine the satisfactory operation of the flight controls and the position of the controls and flaps prior to the crash.

The results of the investigation indicate that the flight controls were functioning without limitations at the time of the crash.

- It was not possible to clearly establish the position of the rudder or elevators.
- It was not possible to clearly establish the position of the ailerons. The parts of the right aileron found in the wreckage at the first point of impact, however, permit the conclusion that the right aileron was deflected downwards, indicating a rotary movement around the aircraft's longitudinal axis to the left.
- The examination of the spoiler system showed that with a high degree of probability the spoiler was extended about one third to the left. This indicates that at the time of impact the aircraft was in a rotary movement to the left.
- The rudder trim tab was extended approximately 1.5° to the right.
- The elevator trim tab was extended upwards by approximately 6°, corresponding to a nose down trim. This setting corresponds to the expected position for horizontal flight at speeds in excess of 300 kt.
- The aileron trim tab was in the area of the neutral position.

Examination of the spoiler system produced the following results:

The piston rod of the left spoiler actuator was partially extended; this corresponded to a spoiler setting of approximately 14° extended (the max. deflection of the spoiler is 40°). This position of the piston rod was confirmed by an x-ray examination. In the course of the forensic investigation, a small notch was found on the inside of the housing section of the control valve. This notch was very probably caused by the control fork of the control valve on initial impact. The position of this notch corresponded to the "left spoiler fully extended" setting. This valve control position was reached at an aileron deflection to the left at an aileron setting of about 14° degrees up (full deflection 17.5°). The piston rod of the right spoiler was found in the "retracted" position.

The examination of the ailerons produced the following results:

Parts of the right aileron were found, extensively destroyed, near the first point of impact. The left aileron was found as a complete component with severe damage behind the embankment point of impact.

The examination of the flap system produced the following result:

The flaps actuator was in flaps up position.

1.12.5.2 Examination of engine PT6A-68 S/N 1712

The engine was examined in detail. The following is a summary of the corresponding investigation report:

The engine exhibited severe impact damage.

The following assemblies were examined more closely because of the axial contact of the rotating parts with the adjacent components:

- 1st stage power turbine vane ring
- 1st stage power turbine
- 2nd stage power turbine vane ring
- 2nd stage power turbine

Radial traces of grinding caused by the deformation of the housing on impact were also found on these parts.

The reduction gearbox propeller shaft coupling had a torque fracture which had occurred as a result of the high load on impact.

No indications were found of pre-existing defects which might have affected normal operation of the engine.

1.13 Medical and pathological information

1.13.1 History and medical findings

According to information from the family doctor as well as from the FOCA medical examiner, the pilot was healthy and in particular free from any cardiac complaints; this was confirmed respectively by the regular examinations and the normal ECG findings. There are no indications in the available medical documents of any medication being taken.

The pilot was known since years to have a refraction defect. He was therefore required to wear lenses or spectacles (VDL). This refraction defect was treated twice by laser therapy on the left eye .With these values, the pilot would not have been fit to fly before the intervention. Fitness to fly could also not been achieved after the intervention. No documents are present concerning a medical examination by an eye specialist as part of the periodic examinations with regard to fitness to fly up to 2004.

The VDL note – must wear spectacles or contact lenses – was present in the medical fitness certificate dated 13.08.2004. The medical examiner made this entry based on the report of the eye surgeon, who had carried out the interventions. At the time of this examination, the pilot did not indicate his eye operation on the corresponding form. According to information from the operating eye specialist, the pilot was no longer advised to wear a vision aid for the left eye after the examination on 17.12.2004. A corrective lens for the right eye was still necessary and was worn regularly.

A copy of the eye specialist's examination report on the FOCA form "*Augenärztlicher Untersuchungsbericht*" completed by the operating eye specialist on 26.03.2004, was found in the medical examiner's records. The operation was not mentioned in this form, nor is the note regarding the need to wear an aid to vision in the right eye present. The eye specialist was neither a FOCA technical expert nor a medical examiner (AME).

1.13.2 Forensic findings

The pilot's corpse underwent a forensic examination.

The pilot died immediately after the accident as a result of the destruction of multiple organs. Survival was impossible, given the numerous injuries and destruction of organs.

The condition of the vital inner organs, despite serious damage, was sufficiently good to allow reliable examination and analysis.

A myocardial bridge 2.5 cm long and 0.7 cm thick was found in the heart above the left coronary artery, just after the outlet from the aorta. On the vessel itself, on the segment under the bridging, there was a considerable intimal plaque formation, though this did not constrict the lumen.

In the supply area of the left coronary artery, no signs of any acute or chronic circulatory disorder were found during examination under the microscope.

Sight defects cannot be determined post mortem, even under detailed examination. The right contact lens, which was probably being worn, could not be found.

All toxicological investigations for alcohol, drugs and medications were negative, i.e. no traces were found.

1.14 Fire

An intense fire broke out on impact with the embankment. Most of the fuel was combusted during this fire. There were no indications of a fire occurring before impact.

1.15 Survival aspects

The impact was not survivable due to the high forces and the resulting injuries.

It was investigated whether rescue should have been possible and survivable by using the ejector seat immediately before the impact.

The Martin Baker A Mk CH16C ejection seat is specified as a so-called 0/0 seat. This means that successful ejection is guaranteed at a speed of 0 kt and a height of 0 ft above ground. For flight conditions which deviate from horizontal flight and 0° bank attitudes, the required minimum height for successful ejection can be determined from corresponding tables which are published in the AFM.

For the aircraft involved in the accident, the following attitude values applied for calculation of the required minimum height using the tables:

- Bank angle 30° - 40° right
- Pitch 0° to -3°
- Speed approx. 300 kt

According to table 21-A-150095-A-S4080-03481-A-01-1 of the AFM PC-21 Draft, the required minimum height for successful ejection was between 0 and 20 feet above ground.

Successful ejection would thus have been just possible immediately before impact. The decision to use the ejector seat to eject would have been required 0.5 to 0.7 seconds before this.

1.16 Tests and research

1.16.1 Analysis of the examinations of non-volatile memories

In the course of collecting evidence, the various items of equipment installed in the cockpit were examined to determine whether installed non-volatile memory (NOVRAM) might have contained information on the last known position, speed and attitude, etc. Although many devices did possess such memories, generally only information on the condition of the unit (health information) is stored.

It was possible to subject the two devices below to analysis, in the course of which certain data which were sought proved to be serviceable:

- the open system mission computer
- the primary flight display (PFD)

1.16.1.1 Analysis of the open system mission computer

The open system mission computer was examined with regard to the content of the NOVRAM. This was intact and could be analysed. In addition to information on the state of the unit, the following information in particular was of significance:

Last recorded position	N46:58,52; E008:24,34	
Last recorded heading	098,5°	
Selected transponder code	3584	
Selected frequencies	COM 1:	1XX.X25 MHz
	COM 2:	119.625 MHz
	NAV 1:	110.350 MHz
	NAV 2:	110.350 MHz
G-forces	Accident flight:	10.900 g
	Previous flight:	3.390 g

It should be noted that the exact time of the last data recording could not be established with certainty, since recording ceased at some point during the destruction of the aircraft.

1.16.1.2 Analysis of the primary flight display (PFD)

The two PFDs from the front and rear cockpit were examined with regard to the NOVRAM content. This was intact in both units and could be analysed.

The recorded data of the NOVRAM correspond to a snapshot of the status 50 seconds after a cold start. Afterwards, only infringements of the pre-set limits for acceleration N_z and speed were registered.

In addition to information on the state of the unit, the following information was retrieved, which show the condition 50 seconds after switching the master switch on. It probably represents the settings used during the preceding flight with two crewmebers on board.

Set configuration	MAP mode; range at 40 NM
Set navigation source	VOR 1
Altimeter setting	1030 mbar
Set decision height (DH)	300 ft

Analysis of the two PFDs produced identical values.

The preset limits of +8g and -4g as well as 329 kt have not been exxeded during the accident flight.

1.16.2 Verification flights

Verification flights were necessary in order to be able to clarify issues regarding flight mechanics, visibility and workload.

For this purpose, a flight test schedule was drawn up. These two flights were carried out over Buochs on 2 November 2005.

The available resources were a PC-21 (P01) and a black PC-9. The light conditions were comparable with those at the time of the accident.

1.16.2.1 Schedule

First flight:

- Horizontal turns up to an accelerated stall at altitudes of 7000, 6000 and 5000 ft AMSL
- Turns with constant acceleration of approximately 3.5 g at altitudes of 4600, 4000, 3000 and 2000 ft AMSL
- Measurement of the roll rate (45° AOB and 60° AOB)
- Loop with an initial altitude of 5000, 4000 and 3000 ft AMSL

Second flight:

- Assessment of the visibility of a black PC-9, by analogy with the black PC-21
- Assessment of the manoeuvre flown at the time of the accident.
- Several repetitions with a gradual reduction of the minimum height to 500 ft

1.16.2.2 Results of the verification flights

Accelerated stall:

In the speed ranges included in the assessment, the manoeuvres flown at altitudes of 5000-7000 ft AMSL exhibited stable flow conditions with no indications of an accelerated stall. For an initial speed of 310 kt at maximum engine power, speed diminished under constant acceleration between 3.5 and 4.5g, so the stall occurred between 206 kt and 200 kt. The stall behaviour exhibited characteristics typical of the PC-21, with an abrupt stall without prior aerodynamic warning and with a rapid roll to the left. The greatest variations in speed that it was possible to fly in the 360-degree turn, with variations in the geometry and speed, fluctuated between 310 and 250 kt. It was not possible to come close to the range which would be critical for stalling. On the basis of this analysis, an accelerated stall (high-speed stall) can be excluded, with a very high degree of probability, as a possible cause of the accident.

Visibility:

In what follows, the visibility of an aircraft which is painted black is assessed under the same environmental conditions from the viewpoint of the aircraft involved in the accident.

In the first half of the 360-degree turn, the black aircraft was not visible when looping the loop, as the first part of the loop was flown in the rear segment of the aircraft executing the 360-degree turn.

In the segment of the 360-degree turn between 180° and 270° the pilot had to establish visual contact with the aircraft in the loop; otherwise the remaining time was not sufficient to estimate correctly the remaining part of the 360-degree turn with regard to the runway centre line and the converging vectors, and to plan the flight path appropriately.

The manoeuvre was flown several times. In the process it was apparent that the black aircraft in the descending segment of the loop never entered the dark background of the Bürgenstock for the pilot on the horizontal 360-degree turn up to the end of the manoeuvre but remained highly visible in the bright sky above the Bürgenstock. Even though the black aircraft was positioned during the last 20 degrees of the loop against the background of the Bürgenstock, the visibility of the black aircraft was not problematical in this phase either, because of the relatively small separation (100 – 400 m).

Summary results:

- In the repetitions of the manoeuvres, no abnormal or restricting behaviour of the PC-21 aircraft type could be detected.
- The visibility of the black aircraft in the second part of the loop was very good.
- Despite the onset of dusk, the light conditions were non-critical.

1.16.3 Investigations of the ejector seat

1.16.3.1 Technical description

A Martin Baker Type Mk CH16C-1 lightweight ejector seat was fitted in the front cockpit of the PC-21 HB-HZB.

Ejection would have been triggered by pulling on the release handle at the front of the seat, between the pilot's legs. This would have resulted in ignition of several launching cartridges and a rocket motor. The sequences of these ignitions and the ignition of the pilot/seat separation cartridge would have been controlled by gas pressure.

In order to guarantee safe ejection of both pilots in the case of a two-man crew, on initialisation of one of the two seats, ejection of the front seat would be delayed. This control system also operated via gas pressure. In the case of a one-man crew, only the front seat would eject, without a delay.

Prior to launch of the ejector seat, the canopy would have been blasted away by means of detonating cord. Since these detonating cords had not yet been fitted to the two prototypes, a canopy of lesser strength was used, through which direct penetration would have been possible without detonation.

1.16.3.2 Situation at the accident site

Front ejector seat:

The front ejector seat was found badly damaged on the east bank of the Engelberger Aa. The parts of the wreckage were 70 metres away from the point of impact on the embankment. The release handle had been torn from its fixing. The stabilising parachute of the ejector seat was deployed. The lines of the pilot rescue parachute were deployed and connected to the pilot harness. The ends of the lines were badly scorched. The chute canopy was missing. The parachute container was in the Engelberger Aa and exhibited major fire damage.

The pilot was found approximately 5 metres from the ejector seat on the east bank of the Engelberger Aa.

Rear ejector seat:

The rear ejector seat was found slightly damaged on "*Buochser Allmend*", approximately 120 metres east of the embankment point of impact, without any visible signs of ignition.

1.16.3.3 Technical investigation of the front ejector seat

1.16.3.3.1 Release handle

The release handle had been torn from its fixing. The mechanism fixed to the release handle had ignited the two cartridges for initialisation of ejection.

The forensic examinations of the release handle produced no indications that the release handle had been pulled by the pilot.

Tests at the manufacturer's premises had shown that in the event of a major vertical impact with 25 g or over, the release handle can separate independently from the interlock and the initialisation cartridges are ignited as a result.

1.16.3.3.2 Ignited cartridges

Of the 17 cartridges installed in the seat, 10 have been fired. The rocket motor was found in the riverbed of the Engelberger Aa and had not ignited.

1.16.3.3.3 Mode selector

The mode selector in the rear cockpit was set to the "solo" position, which means that only the front seat will eject when his release handle is pulled.

1.16.3.3.4 Shoulder belt retraction mechanism

The shoulder belt retraction cartridge mechanism had fired. The lines to retract the shoulder belt were coiled inside the mechanism apart from the last 10 cm. The heavy contamination of the belts and take-up rollers inside the mechanism, caused by grass and soil, indicate that the shoulder belt retraction mechanism cartridge had fired only at the second point of impact.

1.16.3.3.5 Pilot/seat separation

The investigation showed that the cartridges of the pilot/seat separation system were fired on impact with the embankment.

1.16.3.4 Conclusions

Although the front ejector seat release handle was pulled out of its fixing, the pilot was no longer belted to the seat and the cartridge of the shoulder belt retraction mechanism had fired, it can be assumed with a high degree of probability that the ejector seat was not triggered by the pilot.

1.16.4 Investigations on the helmet and visor

During the accident flight, the pilot was wearing an ALPHA 703 type helmet, a product of Helmet Integrated Systems Ltd. It was equipped with two visors, one clear and one dark, as glare protection. In addition, the oxygen mask was fixed to the helmet. The helmet was found in the area between the first and second point of impact. The two visors were found in the vicinity.

The helmet was examined with regard to the position of the two visors at the time of the accident:

According to AFM 02 operating limitations, after arming the ejector seat one of the two helmet visors must be lowered and locked in this position. On the basis of indentations and deformations on the helmet and visors, and from the position of the visor mechanism, it was possible to establish that at the time of impact the position of the transparent visor was approximately 8 cm further down than the dark visor.

The dark visor (glare protection) was in the area of the upper locking position at this time. From this it can be concluded that the transparent visor had been used.

1.17 Organisational and management information

1.17.1 Pilatus Flugzeugwerke – flight operations

Pilatus flight operations were part of the "Research and Development (E)" unit. They were handled by two departments reporting to this unit: the "Flight Test (EA)" department and the "Flight Operations (EF)" department. The "Experimental Shop (AX)" department was responsible for preparing the aircraft.

1.17.1.1 The Flight Test department

The "Flight Test" department was responsible for all test flight activities within Pilatus Flugzeugwerke AG. It drew up the necessary test flight programmes and supervised the flights and the recording of all data. After the flights, it was responsible for preparing and forwarding the captured data.

Before test flights were made, a so-called "Flight Safety Form" (FSF) was produced. This document contained all information on any modifications made and on the operating limits to be complied with. It had to be signed by all departments concerned before the flight was made. This procedure was part of the "design organisation approval (DOA)".

A detailed order, the "flight test order (FTO)", was drawn up for a test flight which was to be carried out. Actual implementation then took place after a detailed briefing by the pilots of the "Flight Operations" department.

1.17.1.2 The Flight Operations department

The "Flight Operations" department carried out all types of works flights within Pilatus Flugzeugwerke. These included verification flights with newly-built aircraft, display flights on behalf of the Marketing department, training flights for works pilots, ferry flights for delivery and test flights on behalf of the "Flight Test" department.

Certain flights served to test newly developed systems and to furnish data for licensing purposes. The performance of these test flights was completely under the control of the "Flight Test" department, whilst the other flights came under the responsibility of the "Flight Operations" department, even if aircraft might not yet have gained type approval.

No entry in the licence was possible for flights by prototypes, as the corresponding type approval did not yet exist. The regulations governing such flights were laid down in the DOA and had been approved by the FOCA.

1.17.2 Pilatus Flugzeugwerke – maintenance of the PC-21 prototypes

Pilatus had its own dedicated workshop, the so-called Experimental Shop (AX). This shop was attached to the production operation and approved by the FOCA within the framework of the production organization exposition under JAR-21. After construction, AX also took over maintenance of these aircraft.

The maintenance regulations for the test flight operation were defined by Pilatus in a technical memo, countersigned by the FOCA as part of the first flight approval and were valid for the two aircraft P01 and P02. The regulations were based predominantly on values acquired from experience of earlier aircraft certifications, taking into account special requirements of new systems, which had never yet been used on a Pilatus aircraft.

1.17.3 Federal Office for Civil Aviation – approval procedure

The Federal Office for Civil Aviation (FOCA), *Sektion Sicherheit, Flugtechnik, Entwicklung und Herstellung STEH* (safety division aircraft, design and manufacturing) was responsible for the civil type approval of the quasi-military trainer PC-21. Pilatus's application for a Swiss type approval was lodged with the FOCA on 4 February 1999.

For reasons of continuity with the Pilatus product line (PC-7 and PC-9 series), the following regulations were applied as a basis for certification:

- US Federal Aviation Regulations Part 23 (FAR-23) Acrobatic Category, including supplements 23-1 to 23-54, valid on 13 December 2000.
- Decree on the airworthiness of aircraft VLL, 748.215.1 (Verordnung über die Lufttüchtigkeit von Luftfahrzeugen – VLL), dated 18 September 1995.
- Decree on emissions from aircraft VEL, 748.215.3 (Verordnung über die Emissionen von Luftfahrzeugen – VEL), dated 10 January 1996.
- ICAO Annex 16, Chapter 10.

A project team which covered all the component sections of the aircraft was assembled under the leadership of the FOCA's project certification manager (PCM).

Pilatus had to produce a master certification programme for the FOCA. This master certification programme, approved by the FOCA, had to show that all the applicable regulations were fulfilled.

In a continuous process during the construction of the aircraft and the test flight period, documentary evidence for type approval was compiled and handed over to the FOCA for checking. The FOCA then decided whether the documentary evidence was complete and conclusive or whether additional clarification and examination were necessary.

Swiss type approval certificate No. F 56-35 was issued on 23 December 2004 by the Federal Office for Civil Aviation for "VFR day". The process for subsequent certification such as for VFR night, IFR and aerobatics was continued.

1.18 Additional information

1.18.1 Formation flights and displays – general considerations

1.18.1.1 Prevention of collisions – the legal basis

The Decree relating to traffic rules for aircraft regulates among others the prevention of collisions in so far as the following points must be complied with regard to separations:

- An aircraft must not be brought so close to another than the risk of collision arises.
- For flights in formation, including take-off and landing, the commanders must reach agreement beforehand.

1.18.1.2 FOCA flying event conditions

In the flying event conditions, the FOCA regulates the conditions and stipulations which must be complied with for public flying events which are subject to authorisation. This document entered into force on 1 May 2003 and since then has been used as a basis for the organisation of flying events, especially major events such as Air04 in Payerne.

There follow a number of key excerpts from this document:

Qualification:

- Only licensed pilots (CPL or at least FI) shall take part in public flying events, in their category. They must be in possession of a corresponding JAA Display Authorisation from their national authority, a special FOCA A authorisation or another display authorisation recognised by the FOCA.
- Aerobatic pilots must be in possession of a valid personal special authorisation A to fly lower than the minimum height.
- Pilots may take part in formation flying only if they have been trained in this and provide evidence of adequate training.

Permitted flying manoeuvres as a function of aircraft categories:

The information below applies to Category II which is relevant to the PC-21 aircraft (propeller or turboprop aircraft with a maximum take-off mass from 1000 kg to 4000 kg).

Cat II	Manoeuvre	Solo	Formation
v_{max}	-	-	-
H_{min}	Normal flying, horizontal, straight	30 m AGL (100 ft AGL) $v_{min} \geq 1.3 * v_s$	30 m AGL (100 ft AGL) $v_{min} \geq 1.3 * v_s$
H_{min}	Aerobatics and evolutions including interception	50 m AGL (150 ft AGL)	50 m AGL (150 ft AGL)
H_{min}	Outside the display centre line	150 m AGL (500 ft AGL) $v_{min} \geq 1.3 * v_s$	150 m AGL (500 ft AGL) $v_{min} \geq 1.3 * v_s$

1.18.1.3 Difficulties specific to formation flying

Systematic training is not provided for formation flying outside the air force. For air force pilots, this type of flying is, of course, part of their everyday activity and corresponding training is provided.

Formation flying places special demands on crews and is accompanied by specific risks. Estimation of relative speeds, distances and vectors in general, as well as awareness of one's own attitude, are central themes and demand intensive training. Essentially, the formation leader has to plan the flying manoeuvre in such a way that a high degree of flight safety is guaranteed. The patrol pilot follows the formation leader. In displays, it is often the case that very small separations between aircraft and heights above ground are chosen.

Visibility conditions have a great effect on the performance of formation flights. For example, the structure of the aircraft may greatly impede outside visibility. In addition, the position of the sun, the weather conditions, the terrain and the colour of other aircraft may affect perception and the ability to estimate.

During the approach phase, attention of the pilot in the approaching aircraft is largely devoted to the other aircraft.

1.18.1.4 The Swiss Air Force PC-7 team training programme

In view of the similarity of the aircraft used and the figures flown, the training of the pilots in the PC-7 team was examined for purposes of comparison.

For several years the Swiss Air Force has had a formation of nine Pilatus PC-7 turboprop aircraft which had participated in many national and international air displays. The pilots in the PC-7 team were recruited from the corps of active jet pilots in the Swiss Air Force.

The PC-7 team had a training programme, defined in writing, which described how new team members were trained. The first two flights took place with two aircraft. Training in close formation flying simpler aerobatic figures at moderate altitudes was provided. The third flight took place with three aircraft at medium and low altitudes. The candidate then completed an introductory flight in low-level aerobatics. A former soloist was used as the flying instructor. If necessary, the flights were repeated.

As part of the one-week PC-7 team training course, the new member was integrated into the overall formation of nine aircraft. In all, 12 to 13 flights were made during this period. The altitudes were progressively reduced to the desired display altitude.

The training of the soloists followed a special programme and consisted of about three flights.

The level of training of the team was continuously assessed during the season by its leader and his commander and if necessary extra training was arranged in addition to the displays.

As a rule, a standard briefing, conducted by the leader, took 15-20 minutes. The commander monitored the flights of the PC-7 team from the ground. His observations and the video recordings formed the basis for the debriefings.

1.18.2 Formation and display flights by the Pilatus company

The Pilatus company organised display flights on the occasion of air fairs and customer events. The special feature of these flights was to highlight the advantages of the respective aircraft, i.e. in particular their performance and manoeuvrability. The flying programme was therefore drawn up accordingly.

1.18.2.1 Display flights with the PC-21

A new display programme was required for the PC-21 aircraft as the latest product from the Pilatus company. A corresponding flying programme was defined in summer 2004 within the flight operation framework. This envisaged using two PC-21 aircraft in formation. The two crews involved in the accident were assigned as pilots. The aim was a first-time display by this formation on the occasion of Air 04 in Payerne in September 2004.

This programme was flown for the first time with both aircraft on 26 August 2004. Five formation-training flights were made at Buochs aerodrome from 26 August to 2 September 2004.

Three flights were made at Air 04 in Payerne from 3 to 5 September 2004.

The flight resulting in the accident was the first training flight by the PC-21 formation after Air 04 in Payerne. In the two weeks prior to the accident, the pilot of P02 trained fairly often solo in low-level aerobatics over Buochs aerodrome.

1.18.3 g - forces

For the level turn, an acceleration of 3-4 g can be assumed. One g corresponds to a mean gravitational acceleration of 9.81 m/s^2. As the acceleration increases, circulation in the head/brain area becomes increasingly worse. The field of vision becomes restricted; there may be a transitory loss of consciousness up to the total loss of consciousness.

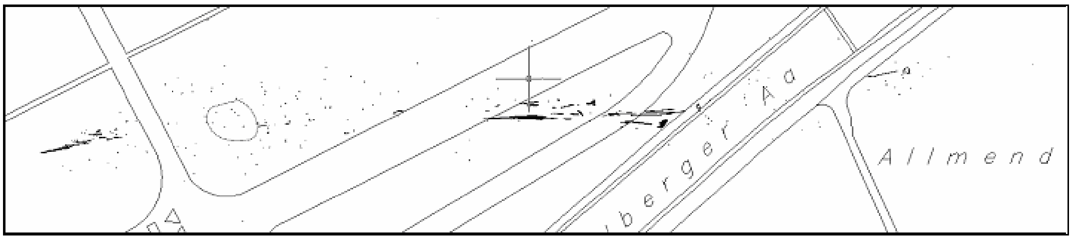
1.18.3.1 g - induced loss of conscious (g-loc)

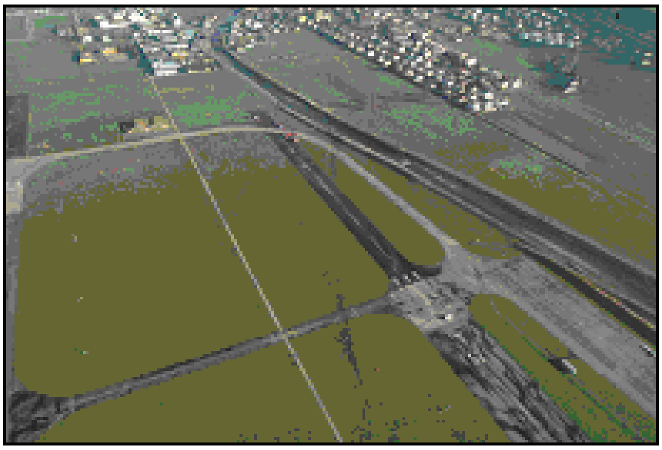
A g- loc corresponds to a complete loss of consciousness in the event of a high, long-term g-force. In very abrupt manoeuvres the rise in g-force may be so fast and strong that loss of consciousness may occur suddenly and without a warning sign. The phenomenon may also occur when an existing high g-force is increased with a high gradient.

1.19 Useful or effective investigation techniques

1.19.1 Survey of the site of the accident using a laser scanner and photogrammetry

The debris field of the Pilatus PC-21 involved in the accident extended from Buochs aerodrome (the point of impact) over the Engelberger Aa (the final position of the pilot involved in the accident) as far as Buochs common (the cockpit). The distance from the first trace of impact to the final measured piece of wreckage was approximately 520 m, with a lateral extent of approximately 110 m.





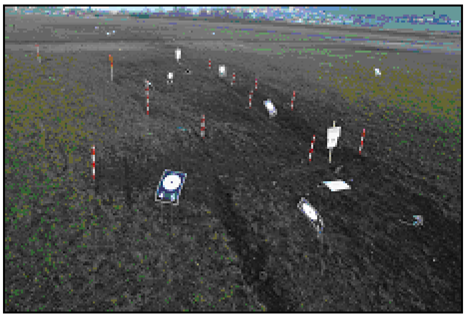
The damage area was surveyed using the following measurement methods:

Photogrammetry was used to survey the traces of impact, skid marks, the aft section of the aircraft, the part of the wing and the cockpit.



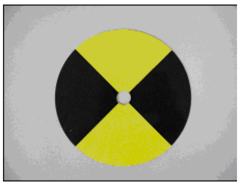

A calibrated survey camera with a resolution of 6.17 million pixels was used to take the survey photographs.

Tachymetry was used to determine the position of the identified parts of the corpse, the technical components and the particular scattered parts of the aircraft. In addition, link points were recorded for photogrammetry, tachymetry and scanning.

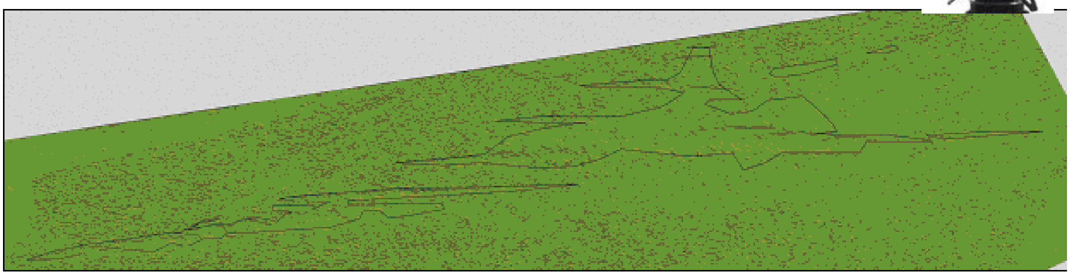


The tachymeter has a range of 10 000 m, with an accuracy of <5 mm, measured on standard prisms. The tachymeter operates in the temperature range from –20 °C to +50 °C.

GPS was used to determine the geographical reference points and the parts which were at a great distance which were pinpointed in the Swiss national system of coordinates for purposes of global orientation. A DGPS with a 12-channel receiver code/phase was used. The recorded points were defined using a specific technical code list. The data accuracy, corrected by post-processing, is about 30 cm.



The primary trace of the impact was recorded in three dimensions with a high resolution **3D laser scanner**. The points measured by the scanner were polygonised and converted into a 3D surface, in which the smallest gouges caused by the impact are precisely recognisable.



The 3D laser scanner is able to scan 360° x 270°, at an accuracy of 6 mm over 50 m.

The data collected at the site from all the instruments employed, was analysed using the appropriate software and assembled into a whole. The Pilatus company provided us with a 3D model, together with plans of the PC-21. The 3D model was additionally completed with the 4 racks which were substantially responsible for registering the traces of the impact.

It was possible to exactly determine the impact sequence of the PC-21 using the model and the traces of the impact, provided with special features (rack lines). Please refer to appendix 4.

2 Analysis

2.1 Technical aspects

The results of the investigation of the parts of the wreckage, the various components of the aircraft controls and the engine produced no indications of any pre-existing technical faults which might have caused the accident.

The marks on the propeller and engine, and the extent of the destruction of the airframe bear witness to a high-speed impact of the aircraft. The damage found can all be explained by the accident sequence.

2.1.1 Position of the ailerons at the time of impact:

Examination of the aircraft control system with regard to the final position of the controls produced the following results:

2.1.1.1 Left spoiler

The nick which was found inside the housing component of the control valve was very probably caused at the time of the initial impact. The position of the control valve's control fork, which matched the nick found in the housing component, just corresponded to a "left spoiler fully extended" control position. This control position was reached at an aileron deflection to the left at an aileron setting of about 14° degrees up (full deflection 17.5°).

2.1.1.2 Ailerons

From the extent of the destruction of the two ailerons and the positions in which they were found after the accident, it can be concluded that on initial impact the right aileron was lowered.

2.1.1.3 Conclusions

The results of the investigation and analysis thereof allow the conclusion that at the time of the initial impact the pilot was on the point of aligning the aircraft after its previous right turn.

It was not possible to establish whether the alignment after the turn took place sharply and as a reaction to perceiving the terrain or as an adaptation to the flight path of the aircraft flying ahead.

2.2 Human and operational aspects

2.2.1 Medical aspects

On the basis of the information from the family doctor and the FOCA medical examiner, the pilot was in excellent health.

2.2.1.1 Vision

According to the applicable national and international regulations (JAR-FCL3), the pilot, with the refraction defect existing before the operation (astigmatism and curvature of the cornea), would have been fit to fly neither before nor after the corrective cornea operation.

At the time of the pilot's initial examination, an eye specialist's examination with accurate refraction measurement was not yet required. Aperently, such an examination did not take place within the framework of the periodic medical fitness examinations either. The pilot should have reported the operations without delay to his competent medical examiner (AME). Such notification did not take place. The AME would have been dependent on such notification in order to be able to decide on subsequent action, as the consequences of such types of laser operation can only be determined during examination by a change in visual acuity. It was not possible to establish why the pilot did not notify the FOCA medical examiner of his two operations.

The possible consequences of such an operation are:

- visual acuity which changes in the course of the day
- increased sensitivity to glare
- decrease in contrast sensitivity

After a corrective corneal operation, it would have been customary according to FOCA practice for the pilot to be designated unfit to fly for at least four weeks.

After this period, fitness to fly could have been reinstated exceptionally subject to the following criteria:

- pre-operative refraction defect within the limits applicable to visual aids
- stable conditions after the operation, i.e. no fluctuations in visual acuity during the day
- no sensitivity to glare
- normal contrast sensitivity
- an application by a FOCA eye specialist to the AMS, decision by the AMS

In the case of the pilot of P02, a refraction defect which would have meant he was unfit to fly – even after a corrective cornea operation – existed prior to 18.12.03.

The result of the operations was documented only incompletely and was not confirmed by a FOCA technical eye specialist. It is not possible to make any statement about the visual capability of the P02 pilot at the time of the accident, particularly with regard to any increased sensitivity to glare or decreased contrast sensitivity.

2.2.1.2 g - forces

Reduced cerebral circulation, which could cause a restriction in the field of vision as a result of a high g-force loading, can never be proved by an autopsy. In order to cause a loss of visual capability, a force of at least 5 to 6 g (1 g = mean gravitational acceleration of 9.81 m/s^2) is needed. A g- force of 6 g and more may cause loss of consciousness. If an anti-g system is used, the g-tolerance is increased.

There were no indications that the anti-g system had not functioned.

In the present case, the average g-force of approximately 3.5 g was not very high.

g-tolerance can be improved, among other things, by intensive training under g forces. In the two weeks before the accident, the pilot of P02 had performed low-level aerobatics quite often.

2.2.1.3 Forensic aspects

The myocardial bridge mentioned in section 1.13.2 above the left coronary artery is a congenital variety; a variation from the norm which is relevant to ischemia under special conditions (obstruction to circulation) which may cause coronary symptoms (heart pains).

Circulatory defects due to such a myocardial bridge as a direct cause of death must be considered as extremely rare. More common, however, are chest pains caused by exertion (pains in the heart), with a normal ECG, which are associated with a myocardial bridge. It is difficult or even impossible to make a clinical diagnosis of such a myocardial bridge, particularly given the absence of pain, a very good general condition and a normal ECG. Appropriate clarification (intracoronary ultrasound, coronarography when subjected to exertion, etc.) is therefore sought only in the event of subjective discomfort or when ECG changes are determined objectively.

Since the pilot had no indications of any kind, subjective or objective, of a heart circulation defect, no such examinations were carried out and the myocardial bridge was accordingly not diagnosed.

In the pilot’s heart, a relatively long segment of a coronary artery ran under a myocardial bridge. It is therefore in principle possible that the artery was compromised under the myocardial bridge as a result of exertion during the aerobatics, the g-forces and the production of stress hormones. This might, likewise temporarily, have led to reduced circulation to the myocardium with acute chest pains (heart pains) and hence to a very brief diversion of concentration, which might have affected or even prevented the correct control of the aircraft. The forensic report considers such a circulation defect, caused by the myocardial bridge, to be possible. However, this cannot be verified by the investigations.

2.2.1.4 Conclusions

The recorded control inputs to exit from the right turn and the clear readability of the last radio communication make any adverse effects due to the above-mentioned medical influences improbable.

2.2.2 Instruction and training

Instruction in aerobatics, followed by instruction in formation flying, is required in the military sphere for flights in formation. In the civil sphere, however, this is not regulated.

The general aviation experience of the pilot of P02 was considerable. In addition, he had completed training in aerobatics, but this had not included any specific training for flying in formation.

In the framework of continuing training courses, consideration was indeed given to the special requirements for testing aircraft. This training did not include any modules on aerobatics or formation flying.

The pilot of P01 was trained in aerobatics and formation flying during his activity in a foreign air force during long years.

Pilatus Flugzeugwerke AG trained its pilots for their activity as display and demonstration pilots.

The planned flight programme was shown at AIR 04 after a corresponding training phase. After AIR 04, no further training flights in formation took place.

When training was resumed, it began with a minimum height of 500 ft QFE and a lateral separation of half the width of the runway. Given such a long interruption in training, an increase in the minimum height and lateral separation would have been appropriate.

The training status must be described as inadequate for carrying out such complex flying manoeuvres in formation.

Apart from the fact that the training was scheduled only one day before the envisaged departure, an additional aggravating factor is that the flight was delayed repeatedly as a result of incomplete maintenance work. This is an indication of a certain pressure.

2.2.3 Multiple responsibilities

Since the pilot of the aircraft involved in the accident had to perform other tasks within the company in addition to his activity as a works pilot, he was unable to concentrate exclusively on carrying out his flights.

As a result of his duel role as chief test pilot and manager flight operations, he bore a heavy professional responsibility. This had increased even further in recent times as a result of his impending departure abroad. However, his quickness of mind and his ability to maintain on overview of his area of responsibility meant that his work colleagues had been persuaded that he would cope with this temporary stress.

2.2.4 Analysis of the manoeuvres flown, visibility and workload

2.2.4.1 Horizontal 360-degree turn and joining manoeuvre, P02

Because of the terrain, the first part of the 360-degree turn up to approximately the end of the first 180° or so was flown in a gentle climb (200 – 300 ft) at a constant acceleration of 3.5 - 4.0 g. Between 180° and 270° of the circular trajectory, the turn was continued, presumably with a glance upward to the culmination point of P01's loop. As soon as visual contact had been made with the aircraft high above in the aft position (loop), the pilot's own flight path had to be managed in such a way that the two flight paths would close, with the necessary safety separation. In this context, extrapolation of the vector of the descending and very quickly accelerating aircraft was very demanding and difficult.

In order to estimate the distance from the 360-degree turn to an aircraft which was rapidly accelerating vertically, the circling pilot had to incorporate in his estimates as an additional reference the right edge of runway 07L, as his lateral safety separation line. This demanded a rapidly repeated glance back and forth between the descending P01 aircraft and his references on the terrain.

A lateral safety separation of 100 m was agreed for the verification flights. The manoeuvres which were being flown ended with a lateral separation of 100 - 200 m, corresponding to a deviation of 100 m. If one assumes that during the flight involved in the accident half the runway width, i.e. about 20 m, had been agreed as the lateral separation, the controlled convergence of the two flight paths has been described as an almost impossible task by the pilot carring out the verification flights.

If, because of the slight delay of aircraft P02 in relation to P01, the pilot had tried to shorten his flight path by pulling in more, this would have led to an increase in the g-force. However, a resulting transitory loss of consciousness can be excluded, as if this had occurred it would have resulted in a relaxation of the muscles, with a reduction in his ability to control the aircraft. As a result, the aircraft would have flown in a tangent out of its envisaged orbital path. However, the initial point indicated, that P02 followed the flight path of P01.

2.2.4.2 Visibility of P01 in the joining manoeuvre

In view of the good visibility established in the verification flights and the radio sequence with the instructions by the pilot in P02, it has to be assumed that visual contact existed from P02 to P01.

Flying in a 360-degree turn with a bank angle of approximately 70 – 75° it was extremely difficult to join up with an aircraft which was levelling out of a dive and accelerating. It is possible that in the final phase of the loop, aircraft P01 and the runway might have disappeared for the pilot of P02 behind the edge of his cockpit, the wing and the fuselage.

In order to maintain visual contact with aircraft P01 during the closing manoeuvre, the pilot of P02 had to assume a position which was to the right of and lower than P01. It must be assumed that P02 wished to maintain constant visual contact with P01 and was therefore in the position described.

The infringement of the agreed minimum altitude by aircraft P01 was detectable only with difficulty by the joining pilot in this phase. Furthermore, in this phase the manoeuvre also did not allow a glance away from the other aircraft to the altimeter display on the HUD or PFD. Thus he was also unable to take in the extreme proximity of the ground. To do this, he would have had to glance to the right above the wing.

2.2.4.3 Analysis of attitudes

The "keep going" radio instruction from the pilot of aircraft P02 involved in the accident allows the conclusion that the pilot of P02 felt able to carry out the joining manoeuvre and the subsequent leader switch.

The radio instruction from P02 – "turn right" – came two seconds later. This instruction was clear and without any indications of a transitory loss of consciousness by the pilot. At this time the pilot of P01 was already flying at a bank angle of 20° right. It must be assumed that the pilot of P02 was concentrating solely on the joining manoeuvre and thus on his position relative to the aircraft in front. He was apparently not aware of the effective attitude and direction of movement in space.

2.2.4.4 P01 loop

One second after the "turn right" message from P02, P01 reached the lowest point of the loop at 180 ft QFE and a radio altitude of 330 ft and began to climb again. The speed was IAS 307 at a bank angle of 23° right.

Presumably, at this time the pilot of P01 had no opportunity to perceive the dangerous position of P02, as the latter was very probably concealed by the wing and/or fuselage.

The distinct infringement of the agreed minimum height of 500 ft and the acceleration sequence indicate that the pilot of P01 did not adequately comply with the intended sequence in the last part of the loop manoeuvre. It has to be assumed that he was looking for visual contact with aircraft P02, to the right. This assumption is supported by the fact that the aircraft was banking 10° - 28° to the right in the last quarter of the loop.

The shallow dive of the aircraft involved in the accident towards the end of its 360-degree turn, observed by eye witnesses could have occurred if the pilot of P02 was using aircraft P01, with its descending instead of horizontal flight path, as a reference. The lateral intersection of the runway centre line to the right in the final quarter of the loop by aircraft P01 may possibly have put the pilot of P02 under pressure and made his joining manoeuvre more difficult, as the reference vector was not only descending, but was also unexpectedly converging with him laterally.

3 Conclusions

3.1 Findings

3.1.1 Technical aspects P01

- The aircraft was admitted for transport as a prototype.
- The video recording from the camera installed on board could be analysed and allowed a reconstruction of the loop which was flown.
- All the flight test instrumentation equipment had been removed from the aircraft for the display flight abroad.

3.1.2 Technical aspects P02

- The aircraft was admitted for transport as a prototype.
- The investigation produced no indication that a technical fault on the aircraft or on the engine was present.
- During the repetition of the manoeuvres during the verification flights, no abnormal or limiting behaviour of the aircraft PC-21 was observed.
- The maintenance regulations for the test flight operation were defined by Pilatus in a technical memo and were accepted by the FOCA within the approval for the first flight.
- The results of the investigations of the flight controls indicate that these were functioning without limitations at the time of the initial impact.
- The left roll spoiler actuator was extended at the time of the impact.
- The right roll spoiler actuator was retracted at the time of the impact.
- The activation of the left roll spoiler actuator indicates that at the time of the initial impact the pilot was on the point of levelling the aircraft after its previous right turn.
- On the basis of checks in the two verification flights, an accelerated stall (high-speed stall) can be excluded as a possible cause of the accident with a very high degree of probability.
- The release handle of the front ejector seat was torn from its fixing by the impact forces during the crash. The partial detonation of the ejector seat munitions which was found was not due to the pilot but was a result of the impact with the ground.
- All the flight test instrumentation equipment had been removed from both aircraft for the display flight abroad.

3.1.3 Crew

- The pilots were in possession of the necessary licences, medical fitness certificates and ratings.
- From the medical viewpoint, the pilot involved in the accident would not have been fit to fly because of the refraction defect in his vision.

- The ascertained control inputs to come out of the right turn and the clear comprehensibility of the last radio conversations make it unlikely that the capacity of the pilot of P02 was adversely affected by ill health.
- The pilots were acquainted with the aircraft and the figure to be flown.
- Unlike pilot P01, pilot P02 had not been systematically trained in formation flying.

3.1.4 Course of the flight

- The accident occurred in the very demanding phase of "joining" after looping and the horizontal 360-degree turn.
- The manoeuvre was very demanding for the pilot of P02 in particular, as his full attention was needed to assess the convergence vectors.
- The pilot of P01 flew as leader (of the formation) in the first phase of the aerobatics programme up to the "joining".
- 500 ft above ground was prescribed as the minimum height. Runway 07L/25R served as the centre line of the display and the road which crossed the aerodrome served as the '*centre*' (the centre of the performance space).
- For the combined loop and horizontal 360-degree turn aerobatic figure, it was agreed that P01 would fly on the runway centre line and that P02 would fly south of the edge of the runway.
- Initiation of the loop took place without a stabilisation phase immediately after the figure that had previously been flown.
- The flight parameters of P01 at the start of the loop were: height indicated on the HUD: 390 ft QFE; height corrected for SSEC: 510 ft QFE; heading: 065° i.e. on runway centre line; lateral displacement: slightly to the right of the runway centre line; attitude: 0°
- The flight parameters of P01 at the end of the loop were: height indicated on the HUD: 180 ft QFE; height corrected for SSEC: 300 ft QFE; heading: 084°; lateral displacement: approx. 140 metres to the right of the runway centre line; attitude: 23° right.
- The pilot of P02 very probably aligned his flight path according to that of aircraft P01.
- At the top of the loop, the pilot of P01 confirmed that he could see the other aircraft with the word "*contact*".
- Three seconds later, when aircraft P02 had flown approximately 210 of its 360-degree turn, its pilot also confirmed that he had the aircraft in the loop in sight with the word "*visual*".
- After a further ten seconds the pilot of P02 asked the pilot of aircraft P01 to continue flying his figure with the words "*keep going*". His position was clearly behind that of aircraft P01.
- Two seconds later, the pilot of P02 again commented on the beginning of the next planned figure, a tight 180-degree turn, with the words "turn right".

- The "keep going" radio instruction from the pilot of aircraft P02 permits the conclusion that he felt able to carry out the joining manoeuvre and the subsequent leader switch.
- It must be assumed that there was visual contact from P02 to P01.

3.1.5 General conditions

- There are no indications that environmental influences affected the course of the accident.
- The flight could not take place until early evening because of trouble rectification on the aircrafts.
- This programme was flown for the first time with both aircraft on 26 August 2004. Five formation-training flights were made at Buochs aerodrome and three display flights were made as part of Air04 in the period from 26.08.2004 to 05.09.2004.
- The flight involved in the accident was the first formation training since the display at Air04.

3.2 Causes

The accident is attributable to a collision with the terrain during an aerobatic formation flight, because the pilot of the aircraft involved in the accident was very probably concentrating on the closing manoeuvre with the other aircraft. In the process, he did not pay attention to his height above the terrain.

The following factors may possibly have contributed to the accident:

- The impairment of the vision of the pilot involved in the accident.
- The pressure of time and the multiple tasks imposed on the pilot.
- The difficulty of the manoeuvre which was being flown.
- The low level of training in formation flying.
- Non-compliance with the agreed altitudes and separations.

Appendices

Appendix 1: Overview of the site of the accident

Appendix 2: Final position of different parts of the wreckage

Appendix 3: Model of the position of the sun and shadows cast

Appendix 4: Simulation of the aircraft impact

Appendix 5: Reconstruction of the two flight paths

Berne, 27 July 2006 Aircraft Accident Investigation Bureau

This report has been prepared solely for the purpose of accident/incident prevention. The legal assessment of accident/incident causes and circumstances is no concern of the incident investigation (Art. 24 of the Air Navigation Law).

Overview of site of the accident

Smoke over the dam of the *Engelberger Aa*

Overview in direction east

First traces of right wing impact

First point of impact and second point of impact plus detached tail in rear

Tail and point of impact on the dam; behind the cockpit in the area of Buochs

Point of impact on the dam of the *Engelberger Aa*

Final position of different parts of the wreckage

Final position of the tail

Final position of wing main- spar / fuel tank section

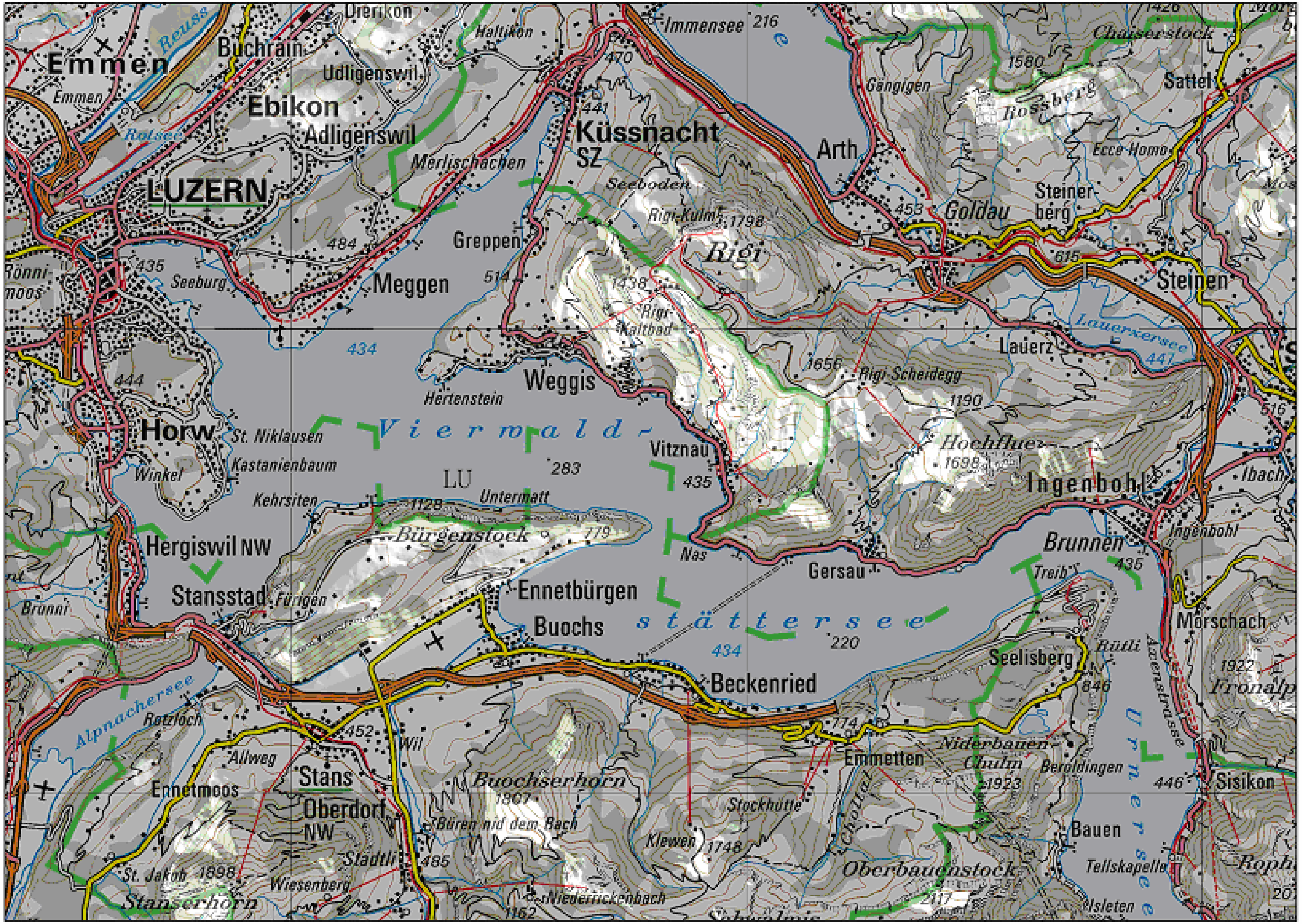
Skin of left wing on the board of the *Engelberger Aa*

Cockpit on the Buochs side of the channel

Engine on the bank of the *Engelberger Aa*

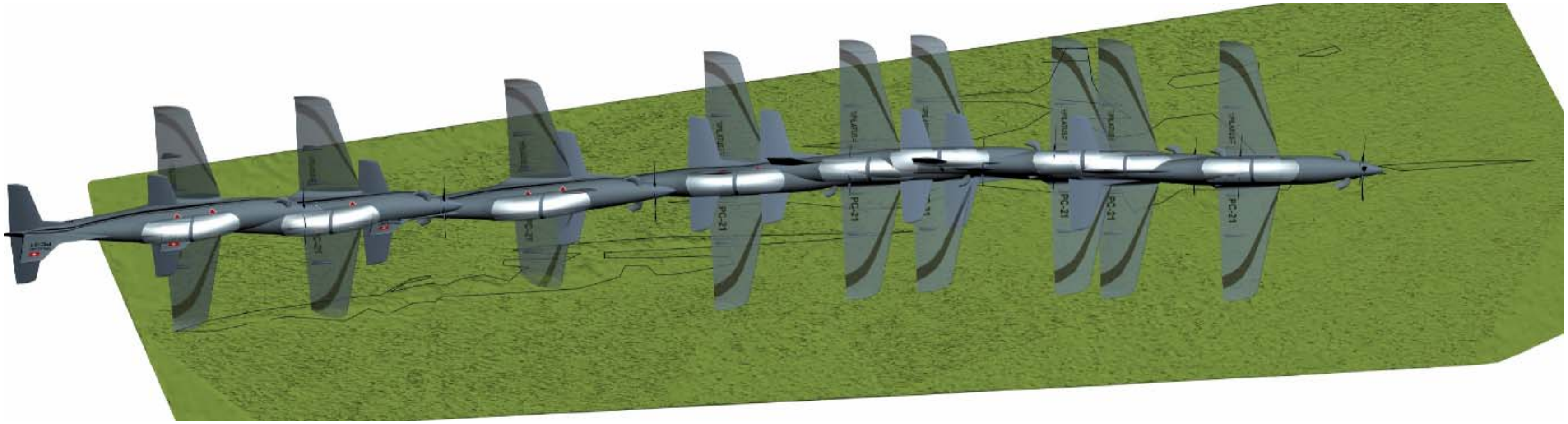
Propeller hub in the *Engelberger Aa*

Model of the position of the sun and shadows cast



Simulation of the aircraft impact

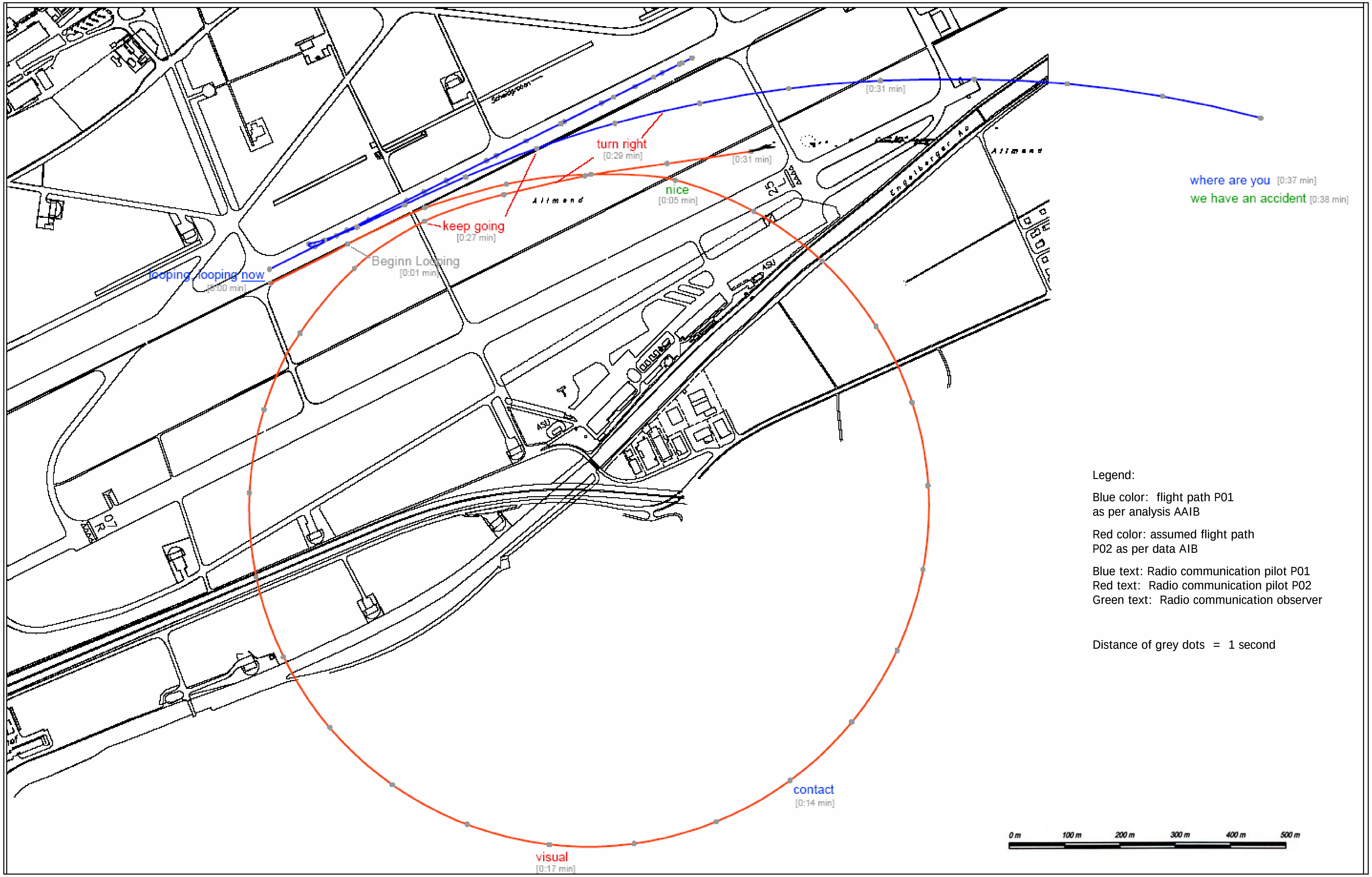
The reproductions below show a plan view and a lateral view of the positions of aircraft P02 from the point of initial impact until leaving the ground anew in the area of the first point of impact.



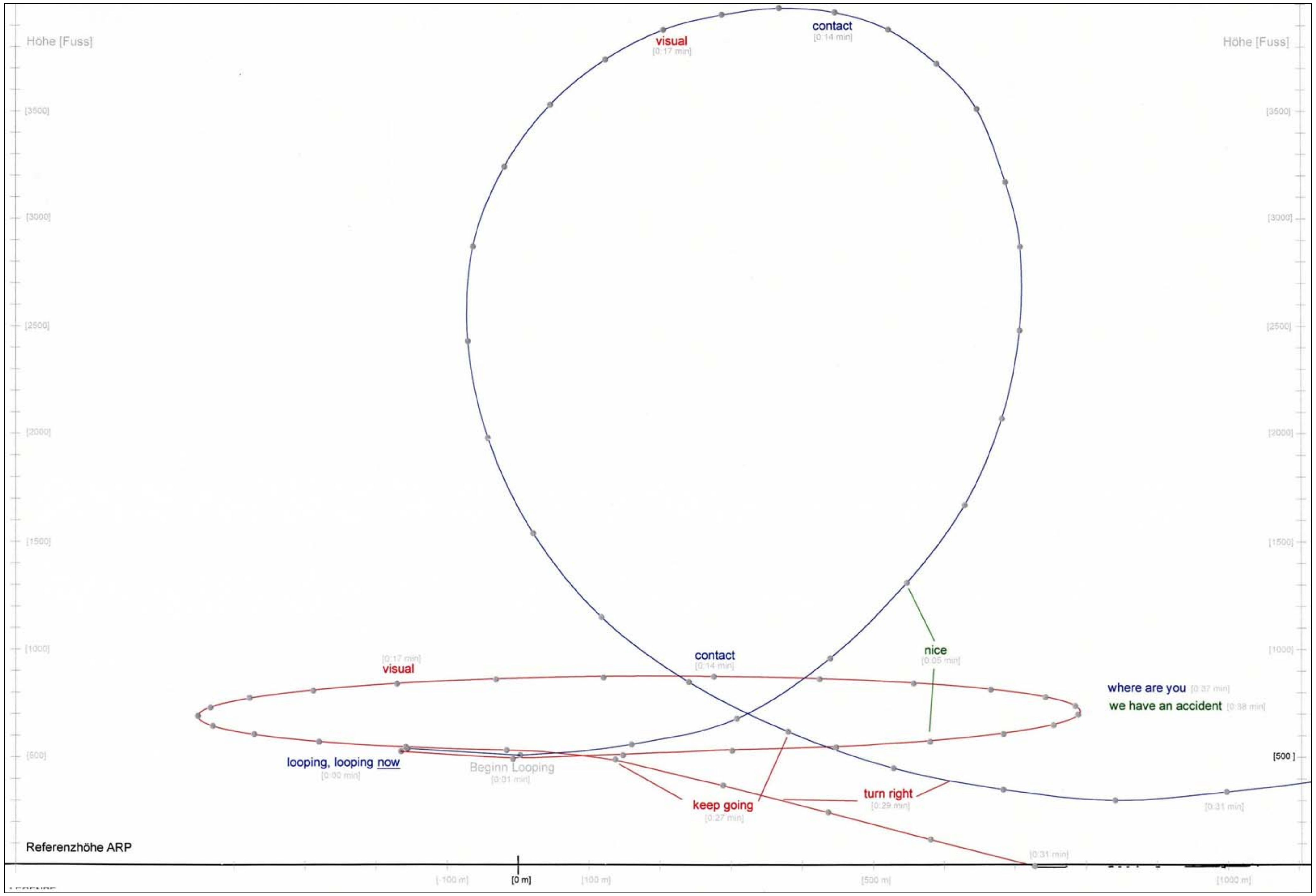
Plan view

Lateral view

Reconstruction of the two flight paths; plan view



Reconstruction of the two flight paths; lateral view



Legend:

Blue color: flight path P01
as per analysis AAIB

Red color: assumed flight path
P02 as per data AIB

Blue text: Radio communication pilot P01
Red text: Radio communication pilot P02
Green text: Radio communication observer

In this drawing, the static source error was accounted for (see 1.6.4.4).

Distance of grey dots = 1 second