ACCIDENT

Aircraft Type and Registration:	YAK-52, RA-3585K
No & Type of Engines:	1 Ivchenko M14P piston engine
Year of Manufacture:	1990
Date & Time (UTC):	28 April 2011 at 1150 hrs
Location:	Langford, near Maldon, Essex
Type of Flight:	Training
Persons on Board:	Crew - 2 Passengers - None
Injuries:	Crew - 2 (Fatal) Passengers - N/A
Nature of Damage:	Aircraft destroyed
Commander's Licence:	Private Pilot's Licence
Commander's Age:	43 years
Commander's Flying Experience:	673 hours (of which 66 were on type) Last 90 days - 20 hours Last 28 days - 10 hours
Information Source:	AAIB Field Investigation

Synopsis

During a tailchase, the aircraft entered an inverted spin at approximately 1,800 ft agl, probably because of unintentional pro-spin positioning of the flying controls. Although the spin ceased after three turns, the aircraft impacted the surface of a lake during the ensuing dive. The investigation identified several factors relevant to the accident, including operation of the aircraft, the type of flight instruments fitted to it and the manner in which the activity was conducted.

History of the flight

The flight took place on the third day of a three-day formation flying school. Weather conditions in the morning were not conducive to the planned flying, and the participants delayed briefing until there was some improvement.

A briefing was given before flight by the instructor who was flying in RA-3585K, and all six pilots in the formation attended it. The content of the flight was to be manoeuvring with the aircraft positioned in vic[1], echelon, and line astern formations, followed by a demonstration of a formation loop and then tailchase by the instructors. The minimum height to be used in the tailchase was 1,000 ft agl. The exercise was to be flown three times, to provide each student with experience in each position in the formation. Other information suggested that because the tailchase had been demonstrated by the instructors during a flight the day before, it was possible that the students would fly the tailchase under the instructors' supervision.

Footnote

[1] A vic formation makes a 'V' shape, flying point-first.

The first part of the flight consisted of manoeuvring, a tailchase and a loop, all in either vic, line astern, or echelon formation. During line astern manoeuvres, RA-3585K was seen to enter mild pilot-induced oscillations around its correct position in the formation, and then to resume a stable and accurate position. An instructor in another aircraft in the formation suggested that the oscillations were consistent with the student handling the controls of RA-3585K, and the correction was an indication that the instructor had taken control. He commented that such oscillations, at that stage of the course, would indicate a relatively slow rate of learning by the student. During this first exercise, RA-3585K was the third aircraft in the formation.

At some later stage during the manoeuvring, perhaps during a formation position change, RA-3585K broke off from the other two aircraft. An instructor in another aircraft recalled that RA-3585K entered cloud and the crew lost sight of the formation. The instructor in RA-3585K called 'out blind'[2], and the three aircraft carried out the applicable pre-briefed procedure. However, in endeavouring to re-join the formation, the crew of RA-3585K found themselves attempting to join up with another formation nearby. Having recognised their error, they reported to the other members of their formation, by radio, that they would not re-join the formation but would instead return to land at North Weald. Following further exchanges by radio, they decided not to return to North Weald but to re-join the formation, and this was then accomplished.

The members of the formation then discussed their fuel states, and decided to conclude the exercises with a short tailchase, before returning to North Weald. RA-3585K was now second in the tailchase of three aircraft.

The lead aircraft was being flown by its student, who had attended the formation school a number of times and was an experienced ex-military pilot. He was manoeuvring his aircraft according to instructions from his instructor.

The tailchase began with a timed break from an echelon-right formation. After the break, the lead aircraft executed wingovers, first to the right, then the left, then to the right, and then again to the left. Just after the apex of the final wingover, the student flying the lead aircraft executed an aileron roll.

The student in the third aircraft was wearing a helmet fitted with a video camera, the recording from which was provided to the AAIB. It showed RA-3585K following the lead aircraft into the final wing-over, pulling up, rolling left towards an inverted position and decelerating, at an altitude of approximately 1,800 ft. The instructor in the aircraft behind commented later that the aircraft:

> *'seemed to pull up a bit steep… and get slow at the top.'*

At the apex of its manoeuvre RA-3585K was seen to reach a low speed and apparently *'very high'* angle of attack. It then progressively rolled and yawed into an inverted spin to the left, which continued for three turns until the aircraft flew out of view of the camera.

Eyewitnesses described the aircraft recovering from the inverted spin into an erect dive at a low height. The aircraft impacted a lake and sank in the water. Another aircraft in the formation transmitted a MAYDAY

Footnote

[2] The 'out blind' call is given by a formation member who breaks away from the formation without maintaining visual contact with the formation.

call to the Distress and Diversion cell at the London Area Control Centre. Emergency services attended, including rescue divers in a search and rescue helicopter who entered the water and located the wreckage. Both occupants had been fatally injured.

Recollections of instructors in the other aircraft

The instructor in the third aircraft interpreted the pull-up into the final wingover as the beginning of a loop, because of the duration of the descent which preceded it and the aggressive pull-up into the manoeuvre. The instructor in the lead aircraft recalled later that the pull-up had been neither particularly aggressive nor weak.

The instructor in the third aircraft commented that during the tailchase, the positioning, anticipation and spacing of RA-3585K in the formation were all good. At no stage did he feel concerned about the manner in which RA-3585K was being flown. He was not able to deduce whether the student or instructor was flying RA-3585K. He offered the opinion that because this tailchase was the second one in the flight during which RA-3585K had flown other than in the lead position, the instructor may have used it as a teaching exercise, not a demonstration exercise, and so either occupant may have been flying RA-3585K. The instructor in the lead aircraft was of the opinion that the tailchase could have been either.

Recorded information

Radar data for the accident flight provided no height information and could not be used to distinguish between the three aircraft with any certainty. GPS data from the third aircraft and footage from the video camera fitted to helmet of the student in this aircraft, which followed RA-3585K during its final wing-over manoeuvre, was analysed.

The video recording was not of sufficiently high quality to enable the attitude or control positions of RA-3585K to be determined. Interpretation of the images was difficult for several reasons, including the presence in shot of the canopy surround, the manoeuvring of the aircraft from which it was taken, the head movements of the student on whose helmet the camera was mounted, and the lack of a constantly-visible local horizon. The combination of the GPS and images did, however, indicate that the manoeuvre was being flown at a GPS altitude of approximately 1,800 ft agl.

Meteorological information

An aftercast provided by the Met Office indicated that around the accident site the visibility was approximately 15 km, the wind at 2,000 ft amsl was north-easterly at 25 to 30 kt, and the cloud base was between three and seven oktas with a base between 1,500 ft and 1,800 ft agl. The Met Office report stated that forecast information which had been available on the day of the accident had been *'broadly consistent'* with the observed phenomena.

Video evidence suggested that the cloudbase may have been slightly higher than this and also showed that there were some sizeable gaps in the cloud.

The formation school

The formation school had taken place twice-yearly for many years at North Weald Aerodrome. The chief flying instructor had a background as a military pilot and flying instructor and examiner.

Training at the school involved first demonstrating new skills to students, then teaching them actively, and then allowing them to practise the skills with assistance from their instructors. As their skills developed, the students would exercise their new skills with reducing

intervention and coaching to the point at which they flew unaided but supervised.

Students and instructors generally attended the school for three consecutive days of flying. Each day students and instructors were organised into pairs and then into formations, typically of three aircraft, for the flying exercises. The student and instructor in RA-3585K had been paired together for all three days of the school, although the student flew once with another instructor.

On the first day of the school, the participants gathered and each one introduced himself, giving a brief description of his flying experience. The chief flying instructor then gave a 'phase brief' which described the purpose of the school and the standard operating procedures. Formations then briefed their activities together before flight and, after flight, debriefs were conducted both as a formation and privately between each instructor and student.

The students were briefed that they were at all times in command of their aircraft, and therefore bore ultimate responsibility for safety. The chief flying instructor described a "contract" between the students and instructors, stating that students should follow the instructions of their instructors, and that their instructors should be given control immediately at any time they requested it, though the student retained responsibility for the safe conduct of the flight.

The school did not have a formal risk management or safety system.

Other organisations ran similar formation flying training events both at North Weald and elsewhere. There was no requirement for such organisations to be approved by the EASA or the CAA and no special regulation of such activities took place.

Standard operating procedures

The organisers of the school had produced a set of standard operating procedures, largely based upon British military formation training procedures, which were circulated to all participants before they attended.

The section on tailchase exercises was as follows:

> *'Tailchasing is defined as a 'follow the leader' exercise. At no time is a tailchase to be allowed to develop into a 'dog fight'. The leader is to nominate a base height below which none of the formation is to descend: this height may be briefed on the ground or in the air, dependent upon the prevailing weather conditions. Members of the formation are not to allow their spacing to reduce to such an extent that the safety of any aircraft in the formation is prejudiced.*
>
> *The following limits are to be applied to tailchasing:*
>
> *a The leader is to maintain VMC at all times*
>
> *b Minimum height 1000 ft agl for experienced pilots, higher limits for ab initios*
>
> *c Minimum vertical clearance from cloud – 500 ft*
>
> *d Minimum spacing – 100 metres*
>
> *e Minimum speed – 150 kph*
>
> *f Leader is to pre-brief min/max G to be used in the tailchase (normally 0-4g)'.*

The power to be set for the tailchase was stated as 80% propeller rpm and 80 cmHg manifold pressure. Pilots were briefed to maintain position in formation without altering the power setting, by using 'lead' and

'lag' techniques. During manoeuvring, the pilot of an aircraft which moved closer to the preceding one would 'lag' by turning or pitching slightly out of the manoeuvre until the correct spacing was once again achieved, and vice versa.

The minimum height employed by the UK military for tailchase training in modern single-engine piston aircraft is 3,000 ft agl. The chief flying instructor commented that the distinction made (in point b, above) between 'experienced' and 'ab initio' pilots was subjective, and could not be measured in terms of flying hours and numbers of flights. He stated that it depended upon an individual student's performance, and how comfortable an instructor felt with that individual.

The procedures included instructions to be followed by pilots flying in formation when visual contact was lost between following and preceding aircraft, intended to ensure safe separation was maintained between aircraft and to enable aircraft to rejoin a formation.

Chief flying instructor's comments

The chief flying instructor stated that for a demonstration tailchase, flown by the instructors, he would expect the minimum height to be 1,000 ft agl, and 1,500 ft agl for a demonstration which was planned to become a teaching and/or practising exercise, with the students handling the controls. He said that tailchases flown early in the school were "very structured" with the objective of teaching students how to maintain position in formation using lead and lag techniques, and would normally consist of two 360° turns at 2g, followed by two wingovers, two barrel rolls and two loops. He stated that for demonstrations the lead aircraft would almost always be flown by the instructor, because a student might not fly sufficiently sensitively to the followers' training needs, but that the lead aircraft student in this case had attended a number of formation schools and could be expected, with assistance from his instructor, to lead the tailchase competently.

The chief flying instructor reviewed the briefing material used for the flight and the previous de-brief records for the pilot, and considered that these were "highly suggestive" that the instructor would be handling the aircraft at the time of the accident. He was shown the video recording of the accident flight and commented that it showed a:

> *'really simple, gentle, tailchase – there didn't seem to be any aggressive manoeuvring at all.'*

The chief flying instructor stated that during a wingover in a tailchase, it was important to keep to one side of the preceding aircraft's flight path, to avoid its wake, and when rolling it was necessary to keep the aircraft's nose pitched so as to keep the preceding aircraft in sight.

With regard to an aileron roll flown by the preceding aircraft, he stated that the following aircraft's pilot need not, and would not be expected to, follow the preceding aircraft's roll. The objective for the following pilot was to follow the preceding aircraft's flight path, not its every manoeuvre.

The chief flying instructor said that he had experienced incipient inverted spin entry "many times" in the Yak-52 during aggressive tailchase manoeuvres. These almost always occured when flying through a preceding aircraft's slipstream at a relatively low speed. He added that the aircraft was immediately responsive to corrective control inputs made by reducing the power to idle and centralising the controls, which prevented the development of a spin entry. He described an inverted spin as "horribly disorientating" and stated that he had

never carried out an inverted spin in a Yak-52, and did not intend to do so, because he would always recover at the incipient stage.

He commented that the aircraft was a "very honest, basic aeroplane" and that the flight regime in which it was operated during the formation school was at the "heart of the envelope". Neither the chief flying instructor, nor other instructors and students interviewed in the course of the investigation, had regarded unintentional spinning as a likely hazard during the formation school exercises. TIt was generally agreed that it was extremely improbable that a student or instructor would execute an intentional inverted spin during a tailchase.

Pilots

Pilots with access to Yak-52 aircraft were able to attend the school as students. They were expected to bring two headsets or helmets and two parachutes with them. The students covered their own costs and the subsistence costs for the instructors, who were not paid for their involvement.

There was no minimum standard of training, competence, experience or recency in aerobatics or recovery from unusual attitudes for the students participating in the 'school' and although each student described his previous experience during a meeting on the first day of the activity, no assessment of ability was made prior to commencement of the activity.

The students were required to be qualified to fly their aircraft as pilot in command. The students flying the aircraft in formation with RA-3585K were in command of their aircraft during the school flights.

The student in RA-3585K

The student had obtained a PPL in 1999. According to his log book and other records, his first exposure to an aerobatic aircraft was in 2008 when he undertook some training on an Extra 200 and then a Slingsby T67 aircraft. This training was planned as the beginning of an aerobatic course and comprised 3 hrs 5 minutes of basic aerobatics including unusual attitudes, an introduction to spinning, and training in loops, aileron rolls and barrel rolls. He did not complete the aerobatic course.

He purchased RA-3585K (then on the British register) in October 2009 and undertook conversion training on the type with an experienced instructor and examiner whose experience on Yak-52 aircraft amounted to 4,300 hours over 30 years, including display flying, and who specialised in training pilots to fly the Yak-52 aircraft.

The instructor agreed to provide a type conversion and safety training. The student had only flown his aircraft twice, with another instructor, to deliver it to its base in the Netherlands. Over four days in April 2010, the two flew slightly less than ten hours, the "vast majority" of which was circuit flying. The instructor commented that it took "rather a long time – about 80 touch-and-gos" before he was sent solo in the circuit. The instructor stated that the student was not in a hurry to be sent solo, but was concerned to achieve a good performance. The two also flew some high angle of attack exercises, stalling, and incipient and one-turn conventional (erect) spins.

The instructor described the student as a slow learner but with a "correct attitude", who made slightly more mistakes than others. His handling skills were "below average". However, he was willing to work very hard to achieve a suitable standard and did not perform unpredictably.

In July 2010, the two flew four further times, concentrating on high angle of attack, stalls, and one-turn conventional spins. On the final flight, accelerated stalls and departures from controlled flight were carried out, but only as "familiarisation". The instructor stated that the student was not proficient in handling departures from controlled flight at the end of the exercises. The two did not fly together again.

Later entries in the student's log book included occasional reference to aerobatic manoeuvres and mention of "spins", against a total of five hours flying which he logged as pilot in command. The investigation found no evidence that he had received training in inverted spins and recovery.

Instructors

Instructors at the school were either military or civilian pilots with extensive formation flying experience; several were current or former military flying instructors with experience in teaching formation flying. A few were experienced Yak-52 pilots, but some only had experience of flying the Yak-52 as rear seat occupants during previous formation schools. Some of them held civilian licences, and some had civil or military instructor qualifications (or both), but some were not qualified to fly or instruct in civilian aircraft. The chief flying instructor stated that the instructors were "safety pilots to help and advise".

Instructors were briefed about technical aspects of the Yak-52 aircraft, including the importance of maintaining balance because of the considerable torque of the engine and propeller combination. They were not provided with any formal flying training in handling the Yak-52 aircraft.

There were no recency requirements for the instructors, either in aerobatic or non-aerobatic flying, or in recovery from unusual attitudes or spins.

The RA-3585K instructor

The rear seat occupant in RA-3585K was a transport aircraft commander in the RAF with experience teaching formation flying, tailchasing, and aerobatics in light aircraft in military service. He held a UK PPL in addition to his military flying qualifications. The investigation found no evidence that he had received training in manoeuvring the Yak-52 close to the limits of its envelope, in spin recovery in the type, or in inverted spinning in any aircraft type.

Although his military flying log books were available to the investigation, no log book of civilian flying was found. Investigators established that he had flown light aircraft, including aerobatic types, in recent years, but it was not possible to quantify this activity or establish its scope. There was no evidence that he had practised inverted spinning. The instructor had participated in the school regularly over the previous five to seven years of its operation, and had also taught at another similar school using a different aircraft type.

One of the other pilots in the formation stated that during the briefing for the flight, another instructor had briefed the instructor that "he needed to pull more g and maintain speed" at the top of a loop, to avoid 'falling out' at the top of the manoeuvre; a loop led by the instructor had reportedly been "a little slow" at the top.

Other participants in the school reported that the instructor and student had been getting on well together, with no signs of tension or disagreement between them, or between them and other participants.

The student and instructor had flown on both preceding days, and the instructor had written notes on the pilot's

sortie report form. The first day's report contained no notes against the heading *'tailchase'*. The second day's report contained a comment against the heading *'tailchase'* which stated that a demonstration of a tailchase had been given, in the lead aircraft position, during which wingovers and barrel rolls had been carried out.

Parachutes

Both occupants wore parachutes. There was no evidence that either occupant had attempted to release his seat harness or abandon the aircraft.

A variety of makes of parachute, with different characteristics, were used by pilots attending the school. Some pilots were not aware of the characteristics of their parachutes. Some owners who had parachutes made in the former Soviet Union had disposed of these because of their weight and replaced them with parachutes of Western design.

Discussions with other participants in the school revealed that the use of these parachutes in this activity was not well understood. Group briefings had not included use of parachutes, minimum abandoning heights, or the relevant procedures. Some pilots had briefed their passengers on parachute use, but there was no evidence of such a briefing between the pilot and rear seat occupant of RA-3585K. One may have taken place unobserved.

Several participants were asked about the minimum heights at which an attempt to evacuate the aircraft would be successful. Some had not given consideration to the question, and various opinions were offered ranging between 1,000 ft and above 3,000 ft agl.

Some pilots involved in the school were concerned that if they abandoned their aircraft, it might then cause harm to persons or property when it crashed.

The AAIB report of an unconnected occurrence[3] during which a pilot successfully abandoned an aircraft at low height, stated:

> *'The pilot had frequently rehearsed the sequence of actions needed to be completed when abandoning the aircraft and was able to exit the aircraft very quickly; a factor which was significant in the successful outcome. Other pilots who wear parachutes may benefit from regular practice and rehearsal of aircraft abandonment drills.'*

Post-mortem examination

A specialist aviation pathologist who carried out post-mortem examination of both pilots found that the crash forces were outside the range of human tolerance and that both had suffered severe multiple injuries on impact. Whilst neither exhibited classical control-type injuries to their hands, the instructor had suffered ankle fractures which might indicate his feet were on the rudder pedals at impact. Toxicology results were negative other than for caffeine.

Aircraft instruments

RA-3585K had original instrumentation in both cockpits, including AGI-1K gyro horizon and DA-30 combined VSI and turn/bank indicator (Figure 1)

The gyro horizon differs from typical western instruments in two principal areas. The horizon ball within the instrument, the face of which is visible to the pilot, is light grey on its lower half and black on the upper; western instruments generally feature a blue upper half, which is relatively lighter, and a brown lower

Footnote

[3] D-FBBD and F-AZDP, reference EW/C2011/07/02, AAIB Bulletin 2/2012.

Figure 1

Instrument panel similar to that fitted to RA-3585K showing gyro horizon (top centre) and combined VSI and turn/bank indicator (top right)

half, which is darker. With the aircraft in inverted flight, and assuming that the gyro horizon had not toppled, the presentation may have looked similar to a western horizon in erect flight. Roll is depicted by motion of the miniature aircraft symbol, not the ball.

The combined VSI and turn/bank indicator has two needles. A solid white needle is read against the white scale inside the rim of the instrument to determine rate of climb or descent. The yellow and black needle is read against the yellow arc above it to determine turn direction and rate.

Spinning the Yak-52

Depending upon the direction of rotation of the engine and propeller combination, aircraft have a tendency to roll in one direction or other under the influence of the engine's torque. The direction of rotation of the Yak 52's engine and propeller induce a roll to the right.

A very experienced Yak-52 pilot and instructor was consulted about the accident spin.

Having viewed the video recording a number of times, he commented that the spin appeared to be a conventional inverted spin, and that from the aircraft's performance he was able to deduce that the controls were in a pro-spin position, as though the spin was executed intentionally. He added that in an inverted spin, even with the control column held fully forward, the spin stops when full opposite rudder is applied. He stated that to maintain an inverted spin, the controls must be held in pro-spin positions. Because of the engine torque, spinning to the left is more difficult to achieve than spinning to the right. He concluded that, assuming there was no malfunction or restriction to the flying controls, the spin entry was definitely either deliberate or the result of mishandling of the controls. This would have been consistent with an attempt to enter a roll from the near-inverted position

visible in the video recording. Had the throttle been closed and the controls centralised or released, the aircraft would not have entered the developed spin. He stated that height loss in a three turn inverted spin with an accurate recovery would be of the order of 2,500 ft.

He later commented:

'I have tried to replicate the entry into inverted spin that was captured on the video.

In the process of the half roll I was gently and progressively applying the left rudder and advancing the stick forward. By the time the aircraft was inverted the rudder was about 80% of the full travel to the left and the stick 80-90% fully forward. During all attempts there was no tendency for the aircraft to enter an inverted spin with this somewhat partial deflection of controls. In each and every case I had to "force" it into the manoeuvre by closing the throttle and applying full left rudder and moving the stick fully forward. The ailerons remained neutral. The timing between reaching the inverted attitude and beginning of the inverted spin was about 3-5 seconds. The development of the spin was normal and very similar to the one shown on the video.

Overall, in all cases the aircraft behaviour was completely usual and as I expected. Of course it is possible to have variations of the entry with different control inputs, for example, ailerons to both sides and different power settings. However, through all of my flying with the Yak-52, I never witnessed unexpected strong tendency of the aircraft to develop an inverted spin from inverted flight. The controls should be in a pro-spin position in order to induce the entry. A mishandled stall turn may lead to unexpected inverted spin; I've seen this a number of times. But there again, the rudder is normally fully to the right and the stick is fully forward and to the left. This is a different scenario.'

Regarding parachutes, he stated that the original Russian manual for the aircraft suggested 3,300 ft agl as a minimum abandon height, but that particular types and brands of parachute had their own, lower, limits. He reported that according to training he had received, the lowest minimum height for parachute exit was 180 ft agl[4] assuming a speed of 220 kph and immediate parachute deployment by hand; at 120 kph the height was 210 ft agl; using an automatic opening device set to 2 secs delay, the minimum height was 360 ft agl. He stated that he viewed the probability of successful parachute descent as being very high, but that in the Soviet Union, where he had learnt to fly the Yak-52, all pilots were required to make a parachute jump every year, which built confidence and minimised delay in action should parachute use be necessary while flying.

Engineering investigation

Accident site and initial examination

The aircraft had come to rest submerged in a small lake, approximately 30 metres from the shore. Examination of the wreckage by divers confirmed that the aircraft was lying inverted on the lake bed. The right wing had separated from the fuselage and the left wing had failed approximately eight feet from the wing root.

An initial examination of the aircraft was carried out after recovery from the lake. The engine mounting

Footnote

[4] All heights mentioned in this paragraph are approximate conversions from metric values.

structure had failed and the engine had been pushed back into the engine bay firewall and displaced to the left. The right wing structure had failed at the wing root and the adjacent fuselage structure was severely damaged. The damage to the fuselage structure had resulted in failure of the forward cockpit shoulder harness attachment structure.

The remains of the right wing exhibited significant leading edge damage and the right main landing gear was in the UP position. The right wing flap had been torn from its mounting structure. The left wing had failed immediately outboard of the flaps and the leading edge of the wing had been compressed and pushed upwards. The left wing flap and the left main landing gear were in the UP position. The continuity of the rudder and elevator control circuits was confirmed.

Sections of the aircraft's propeller had been recovered from the surface of the lake, one of which exhibited leading edge damage, consistent with the propeller blade striking a tree branch whilst rotating. Examination of the trees surrounding the lake failed to identify any areas of damage to their branches.

The aircraft fuel tanks had ruptured, and no fuel samples were recovered, but significant fuel contamination of the lake surface was apparent. The continuity of the engine throttle and propeller pitch control system was confirmed from both crew positions to the engine. Both throttle levers were in the fully forward (full power) position and the propeller pitch control selectors were in the FINE pitch position. No witness marks were found within ether system to confirm the position of these controls at impact.

Both occupants had been wearing parachutes and their harnesses, including the crotch strap, and the rudder pedal foot straps were securely fastened. The damage to the fuselage had resulted in failure of the forward cockpit shoulder harness mounting structure. One section of the mounting bracket for the rear cockpit shoulder harness had failed, releasing the right shoulder harness strap. The left shoulder harness strap had failed approximately 30 cm from its attachment point.

Detailed examination

Reconstruction of the aileron control circuits showed no evidence of a pre-impact restriction or defect. Damage to the aileron bell-cranks, located in the outer wings, was consistent with the application of a left wing down aileron input at impact. Examination of the flap selection and extension system confirmed that both flaps had been in the UP position.

Measurement of the propeller blade pitch angle indicated that the propeller blades had been close to the fine pitch position (14.5°) at the time of the impact. There was no evidence of a major malfunction within the engine; examination of the spark plugs showed no evidence of abnormal operation.

The impact forces and the failure of the engine mounting structure during the impact had resulted in significant damage to the engine accessories which prevented testing of the engine ignition systems, the propeller governor and the carburettor. Examination of these components did not identify any evidence of pre-impact defects.

Examination of the failed shoulder harness strap from the rear cockpit confirmed that it had failed in overload. No defects were identified with the material of the harness. Metallurgical examination of the rear cockpit shoulder harness attachment bracket did not identify any abnormalities in the bracket and confirmed that it had failed in overload. The seat harnesses and

attachments fitted to RA-3585K were designed to withstand loads up to 16 g. Post-mortem examination of the two occupants of the aircraft indicated that the impact forces were significantly in excess of this value.

Registration history of the aircraft

Shortly after purchasing the aircraft the owner moved it from the UK, and based it in the Netherlands. The aircraft was removed from the UK register and placed on the register of the Federation of Amateur Aviators of Russia as RA-3585K. This organisation issued a Certificate of Airworthiness for the aircraft on 30 January 2011.

Prior to bringing RA-3585K into the UK to undertake the training course, the owner applied to the UK CAA for approval to operate the aircraft within UK airspace. This application was approved based, in part, on the aircraft holding a current Certificate of Airworthiness.

Enquiries made to the Russian Federation by the AAIB during the course of this investigation have identified that the Federation of Amateur Aviators of Russia is not authorised by the Russian CAA to issue Certificates of Airworthiness for general aviation aircraft.

The issues relating to the registration of this aircraft will be dealt with in a separate AAIB study.

Analysis

Engineering

The damage to the aircraft was consistent with it striking the surface of the lake upright with a nose-down attitude of approximately 45° and the right wing low. Witness marks on the aileron control circuit indicated that attempts were being made to roll the aircraft into a "wings level" position at impact.

The impact forces resulted in the right wing and the outboard section of the left wing separating from the airframe. The damage to the fuselage caused by the separation of the right wing resulted in the failure of the forward cockpit shoulder harness attachment structure. The force of the impact exceeded the ultimate load of the rear cockpit shoulder harness and its attachment bracket and resulted in their failure.

There was no evidence of any pre-impact defect or restriction within the flight control systems, although the presence of a restriction could not be entirely ruled out.

Whilst the position of the engine and propeller controls at the time of impact could not be verified, there was no evidence of a failure or abnormal operation of the aircraft's engine, carburettor or the propeller governor. The video recording showed that the propeller was rotating as the aircraft entered the inverted spin. Although no estimation of the propeller's rotational speed at impact could be made, the fact that the propeller blades were close to the FINE pitch position indicated that the propeller rpm at impact was high.

Operation

The flight progressed uneventfully until, some time before the accident manoeuvre, the crew of RA-3585K lost visual contact with the preceding aircraft and broke away from the formation. The school had specified procedures which were to be followed by the pilots of the three aircraft. The crew of RA-3585K apparently mistook another formation of two aircraft for their own, and attempted to join it, before declaring a decision to return to North Weald without completing the planned exercises.

RA-3585K subsequently re-joined the correct

formation, and a decision was taken collectively to conclude the flight with a tailchase. The school's usual tailchase sequence was not followed, and the tailchase began with a series of four wingovers. Although it was not usual for the lead aircraft to be flown by the student, the student in this case was relatively experienced and executed the manoeuvres according to his instructor's commands.

The instructor in the lead aircraft recalled that the pull-up into the final wingover was not remarkable; the instructor in the third aircraft perceived it to have been sufficiently aggressive to have come to the conclusion that a loop was to be performed. If the pull-up was more aggressive than usual, it may have led to RA-3585K's speed being lower than usual, and rate of deceleration being greater, at the apex of the wingover.

The entry into the inverted spin was gradual and progressive, and not consistent with a flick manoeuvre resulting from a wake encounter, although participants in the formation school had experienced incipient spins in those circumstances.

Evidence from the experienced Yak-52 pilot and instructor suggested that pro-spin control inputs, at least of rudder and elevator, were necessary to achieve an inverted spin. While the engineering investigation did not rule out some form of control restriction, it is unlikely that one restriction would affect both controls at the precise moment that pro-spin inputs were being applied. The direction of roll into the spin was contrary to the direction in which a torque-induced roll would develop, so it is likely that the spin was entered because the controls were positioned to cause it.

The roll executed immediately after the apex of the wingover by the lead aircraft was not in keeping with the usual tailchase format, and may not have been expected by the crew of RA-3585K. As RA-3585K reached the apex of its wingover, in or close to an inverted position, with the speed low and reducing, the rolling manoeuvre flown by the lead aircraft may have caused momentary confusion. It is possible that control inputs were made by the pilot flying RA-3585K to roll the aircraft prematurely, or to pitch and roll the aircraft to maintain visual contact with the lead aircraft as it executed its roll.

It was not possible to determine whether the student or instructor in RA-3585K was handling the controls during the wingover.

If the student was flying the aircraft, it is possible that his limited experience in aerobatics and recovery from unusual attitudes contributed to a loss of control. This limited experience, and the presence of the more experienced instructor, may have prevented the student from ensuring that the flight remained comfortably within his abilities, or from taking control to prevent or recover from the departure from controlled flight. In that case, the outcome may have been different if an appropriate minimum standard of competence, especially in aerobatic manoeuvres or recovery from unusual attitudes, had been set for participant students.

If the instructor was flying the aircraft, it is possible that his limited experience in aerobatic flying in the Yak-52 and recovery from unusual attitudes in the type may have caused him to reach too low a speed at the apex of the wingover. Another instructor had discussed speed at the top of a loop with him in the briefing prior to the flight, highlighting that he had not pulled hard enough in that manoeuvre. This limited experience may also have delayed or prevented his recognition of the impending departure from controlled flight.

No training in handling the aircraft, in particular in recovery from unusual attitudes or spins, was provided to instructors. Training and experienced in handling the Yak-52 aircraft, particularly in recovery from unusual attitudes and spins, might have been beneficial in this regard.

The aircraft impacted the water in a dive following recovery from the inverted spin. Had the same recovery begun at sufficient height, the aircraft would not have impacted the water. The minimum height for tailchases chosen by the formation school provided a smaller margin for recovery than that used by the UK military.

If the students were intended to be in command throughout the exercises, and thus responsible for maintaining safe control of the aircraft throughout, it would be reasonable for steps to be taken to ensure that the aircraft were only manoeuvred within the students' own experience, ability, and confidence. The investigation did not identify any mechanism by which this was achieved.

Although the participating students were told that they remained in command throughout, they were expected to cede control to their instructors when the instructors requested it, and were aware that their instructors were generally much more experienced in aerobatic and formation manoeuvres than the students. Ambiguity as to who would control the aircraft may have delayed action to recover from the inverted spin.

Inverted spinning is known to be a disorientating experience, and the spin in this case continued for at least three turns. The student and instructor's lack of experience in inverted spinning may have delayed effective recovery action.

The gyro horizon and combined VSI and turn/bank indicator presented information in a different style to the instruments typically found in the aircraft with which the instructor was familiar. Had he consulted these instruments around the time at which the spin entry occurred, or endeavoured to determine the direction of spin from the turn co-ordinator, the presentations may have confused him or delayed his action.

It is unlikely that the spin entry was intentional because this was not consistent with the briefed exercise, would not have enabled continuation of the tailchase and given the entry height, would have been hazardous.

Although both occupants wore parachutes, there was no evidence of an attempt to abandon the aircraft and witnesses indicated that little attention had been paid by participants in the formation school to the use of parachutes. Had the occupants of RA-3585K attempted to abandon the aircraft when control was lost or shortly thereafter, fatalities may have been prevented. The AAIB has reported previously that pilots who wear parachutes may benefit from regular practice and rehearsal of aircraft abandonment drills.

The school advised the AAIB that it had introduced a number of measures in light of the accident, including:

- Compulsory aircraft abandonment practice drills for all participants, with a full briefing from the student to the instructor on the operation and operating envelope of the particular parachute used in the aircraft.
- A more formal and recorded method for establishing student previous experience.
- The minimum tail chase height has been increased to 3000 ft regardless of experience.

- Instructor training (in the form of lecture and discussion) on the spin (all modes) and low speed characteristics has taken place and refresher training will be conducted at each school.

- The main phase briefing on day one has been expanded to include a fuller discussion on the roles of the aircraft commander and the instructor.

Conclusions

The aircraft impacted a lake during the recovery from an inverted spin. No technical malfunction or defect was identified to account for the accident and it was not possible to determine which occupant was handling the controls during the spin entry or recovery. It is likely the spin entry was not intentional but began when the flying controls were placed into pro-spin positions with the aircraft inverted, at low speed and high angle of attack. Recovery may have been adversely affected by the occupants' unfamiliarity with the manoeuvre, ambiguity as to who had control, and flight instrument presentations. The aircraft impacted the lake before the recovery could be completed.