ACCIDENT

Aircraft Type and Registration:	Pitts S-2A Pitts Special, G-ODDS
No & Type of Engines:	1 Lycoming AEIO-360-A1E piston engine
Year of Manufacture:	1980 (Serial no: 2225)
Date & Time (UTC):	24 August 2019 at 1304 hrs
Location:	Stonor, Oxfordshire
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 (Class Rating Instructor)
Commander's Age:	35 years
Commander's Flying Experience:	Approximately 710 hours (of which about 172 hours were on type) Last 90 days - 35 hours Last 28 days - 12 hours
Student's Flying Experience:	197 hours (of which 1 hour 25 minutes were on type) Last 90 days - 34 hours Last 28 days - 8 hours
Information Source:	AAIB Field Investigation

Synopsis

During an aerobatics training flight, the aircraft struck the ground whilst in a spin. The aircraft was destroyed and both pilots were fatally injured. A definitive cause could not be determined, but it is likely that the commander became incapacitated during a spin and the student was unable to recover the aircraft in time. The aircraft had a Centre of Gravity (C of G) position that was out of limits aft, which would have reduced the capability of the aircraft to recover and extended the time to do so. Unapproved devices, which adjusted the rudder pedal positions, were found on the rudder cables but were unlikely to have been a contributory factor.

Safety action has been taken by the operator regarding aircraft weight and balance to ensure accurate weights are used.

History of the flight

The aircraft was engaged on an aerobatic training sortie. The objective of the training was to prepare the student to compete in Sports[1] level aerobatic competitions. The accident occurred on his third sortie of the training and the student was operating from the rear cockpit of the aircraft.

The exact content of the sortie is unknown, though the investigation was advised that the commander generally followed the Aircraft Owners and Pilots Association (AOPA) Standard Aerobatic Course syllabus. For the stage of training being undertaken, it is believed that upset recovery training and recovery from inadvertent spin entry would have been likely exercises.

The aircraft took off from White Waltham Airfield at approximately 1255 hrs. It flew to an area north of Henley-on-Thames and was seen manoeuvring by two eyewitnesses. The eyewitnesses described the aircraft as entering a spin and then recovering, climbing to gain more altitude and then entering another spin. The eyewitnesses were both over one mile from the accident site. Their statements differ significantly in the estimation of the height of the aircraft and the exact manoeuvres flown, though both recalled last seeing the aircraft in a spin. The second spin persisted for several turns and the aircraft was still spinning when the witnesses lost sight of it; neither witness saw the aircraft strike the ground. Both occupants were fatally injured.

Accident site

The accident site was approximately 1 mile south of Stonor village in an open field with livestock (Figure 1). The aircraft was disrupted, in an upright position and had struck the ground in a steep nose-down attitude. The ground marks showed the first ground contact was made by the leading edge of the right lower wing and the nose of the aircraft. The ground marks were short and although the ground was very hard, the aircraft had not travelled forward after the initial contact. However, there was evidence that the aircraft had moved to the left by approximately 1-2 m with a small rotation to the right which is consistent with spinning with right yaw. Both pilots were restrained within the aircraft but had suffered injuries which were not survivable.

Footnote

1 There are four contest classes of aerobatic competition of which Sports is the lowest and requires only basic aerobatic manoeuvres.

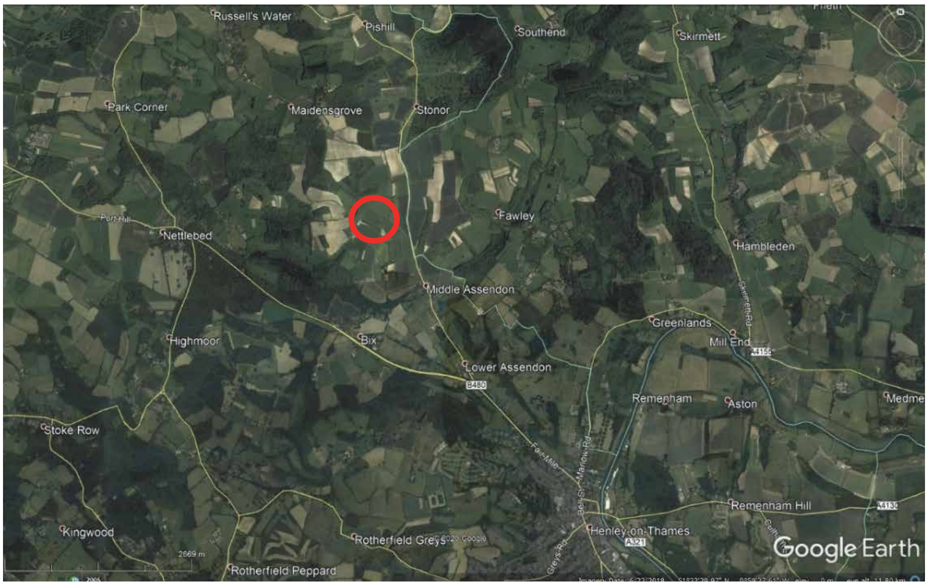

Figure 1
Accident site

Recorded information

The only sources of data relating to the flight were primary radar recordings (Figure 2). This provided the aircraft flight path but no altitude information. Radar contact was lost at 1304 hrs.

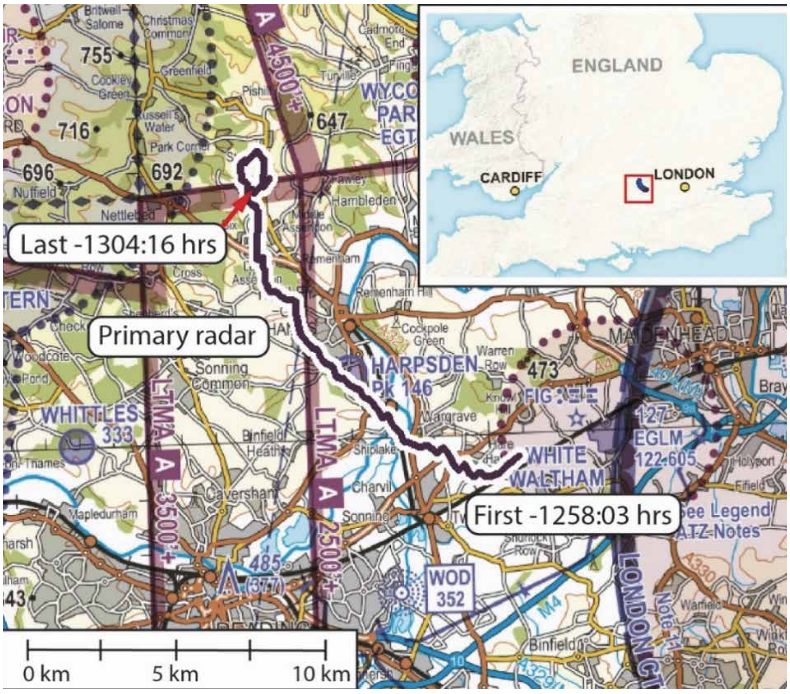

Figure 2
Radar data

Airspace information

The aircraft was being flown in Class G airspace. However, the London TMA, Class A airspace, lies over the area in which the aircraft came to rest and has a lower level of 3,500 ft amsl. The terrain at the accident site rises to approximately 500 ft amsl, so the base of the Class A airspace is approximately 3,000 ft agl. The Benson Military Air Traffic Zone and further Class A airspace at 4,500 ft amsl lies to the west of the accident site. Approximately 500 m north of the accident site the base of Class A airspace rises to 5,500 ft amsl.

Meteorology

The Met Office conducted an analysis of the meteorological situation. A summary is as follows:

> *'From the information available, it can be concluded that weather conditions around the Stonor area in Oxfordshire, on Saturday 24th August 2019 at around 1305 UTC were very benign. Visibility was likely to be greater than 10KM, likely up to 30KM, and there would have been very little cloud, if any. Although neither RAF Benson, nor RAF Northolt reported any low or medium cloud, there is a chance that at the location of interest, there could have been some Cumulus or Stratocumulus between 2000FT and 5000FT.'*

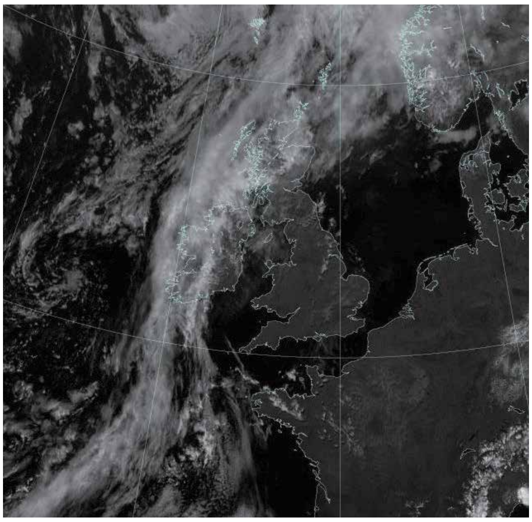

Figure 3

Visible Light Satellite images 1300 hrs, 24 August 2019

Personnel

The commander was a PPL(A) holder with a current Class 2 medical, an aerobatics rating, a Class Rating Instructor and was an Unlimited Category competition aerobatics pilot. The results of an electrocardiogram (ECG) examination, carried out in 2001, were acceptable for all classes of aviation medical[2]. The commander's previous logbook was not found and

Footnote

2 The commander had a Class 2 Medical for which a retest of the ECG was not required until age 40.

so the flying hours experience on the Pitts Special is an approximation based on the active logbook and information provided by the operator.

The student was a PPL(A) holder, endorsed with night and aerobatic ratings, with a current Class 2 medical. The aerobatic rating course requires a minimum of 5 hours or 20 flights of airborne instruction in aerobatics[3] ; the syllabus included spin training. The student only flew with the accident commander as the operator had assessed that flying with any other instructor would have resulted in their combined weights exceeding the weight limit for aerobatics for the aircraft.

Medical aspects

The post-mortem for the student indicated no issues that would have been a factor in the flight while that for the commander revealed a significant cardiac condition. While there were no indications of a previous heart attack, there was significant narrowing of a cardiac artery. The level of coronary disease could have placed the commander at risk of sudden death due to cardiac dysrhythmia. Most cases of such disease in young people are generally only identified at post-mortem with no history of previous symptoms. The condition is not common and particularly rare in those under 40. The commander had shown no history of illness and it is unlikely the condition would have been revealed by an ECG unless a significant physiological burden[4] was applied at the time. Such testing is only required for pilots over 65 for a Class 1 aviation medical.

It is possible that the commander could have suffered a significant alteration of cardiac output, sufficient to prevent further control of the aircraft. In this eventuality it would be likely that the commander would have collapsed with little or no warning.

Aircraft information

The Pitts Special S-2A is a two-seat aerobatic biplane designed in the 1940s and has a proven record in aerobatic competition flying. G-ODDS was built in 1980 and was fitted with a Lycoming AEIO-360-A1E engine.

Fuel consumption

The AOPA Technical Companion for the Pitts S-2A gives an approximate fuel burn of 50 litres per hour for aerobatic training and a minimum fuel for aerobatics of 20 litres. There is approximately 3.8 litres of unusable fuel.

Rudder system

The rudder is operated by two steel cables running the length of the aircraft, which are connected to two sets of pedals, one set in each cockpit. When the left pedal is pushed forward, the cable pulls on a lever attached to the rudder and moves the rudder to the left, and visa-versa. As the left pedal is pushed forwards, the right pedal will be pulled backwards, with the pedals in both cockpits moving simultaneously. Figure 4 shows the system with an inset view, looking forward on the front cockpit, from an exemplar aircraft.

Footnote

3 Part FCL 800.b.2.ii
4 https://www.bhf.org.uk/informationsupport/tests/exercise-ecg [accessed 16 October 2020]

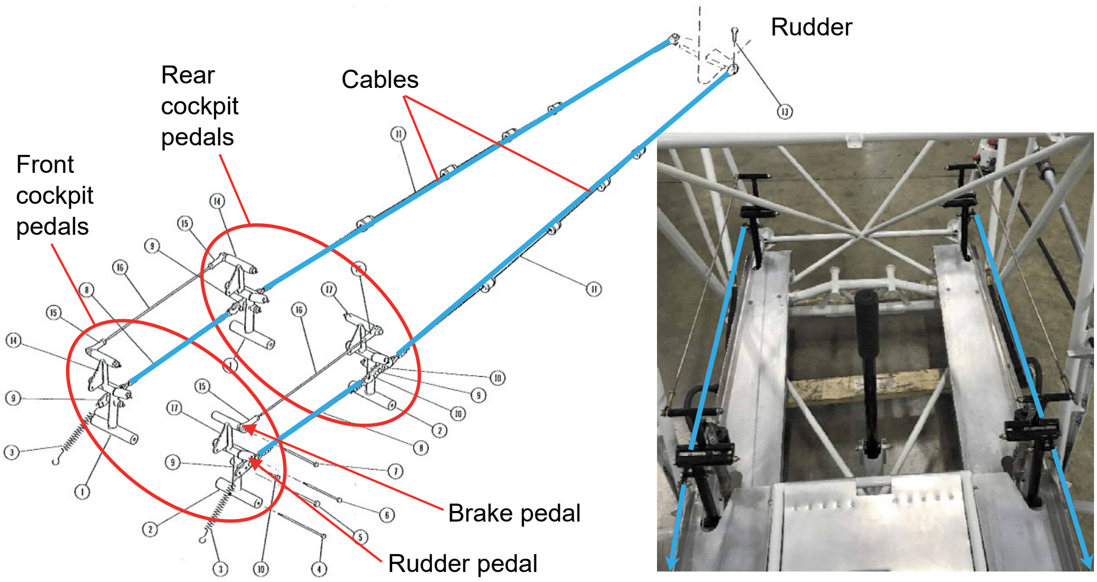

Figure 4

Rudder control system schematic and cockpit view looking forward in an exemplar aircraft

The airframe is a welded tubular steel construction with a fabric covering and sheet aluminium trays in the cockpits for the pilot's feet to rest upon. The rudder pedal hinges are welded to the frame and there are cut-outs in the trays to allow for pedal movement (Figure 5). The cut-outs in the trays allow for the full movement of the pedals and the rudder of +/- 30° without restriction. The brake pedals, which actuate the hydraulic brake system, are mounted on top of the rudder pedals. No adjustment of the pedal position or seat position to suit the pilot is possible.

Figure 5

Front rudder and brake pedal and heel tray cut-out (side and top view of exemplar aircraft)

Aircraft examination

The aircraft was recovered to the AAIB facilities for detailed examination of the airframe and engine. No anomalies were found with the airframe structure or with the engine. It was not possible to examine the accessories fitted to the rear of the engine as they were all extensively damaged. The three-bladed propeller had sustained damage to one blade (which had lost its outer third), one entire blade was missing, and the third blade was undamaged. In the rear cockpit, in the top of the airframe, was a storage locker which contained several items that weighed 1.36 kg (3.0 lb) in total.

Both pilots were sitting on top of additional seat cushions made from layers of firm closed-cell foam approximately 25 mm thick per layer. In the front cockpit, seven cushions were present and, in the rear cockpit, three cushions were used. All the additional cushions were retained by the five-point seat belts and, in total, weighed 1.9 kg (4.2 lb).

All the control cables were inspected and found intact. However, the control column in the rear cockpit had become detached near the hinge point. It was observed that there was impact damage to the left rudder surface (Figure 6) with corresponding damage to the left elevator. The rudder stops were present and undamaged, and the trim tab was set to neutral.

Figure 6
Elevator and rudder damage (circled)

Rudder cable devices

During the initial examination of the aircraft at the accident site it was noted that there were four unidentified devices fitted onto the rudder cables. They were left in place for further examination at the AAIB facilities. A device was fitted on each of the cables between the forward and rear rudder pedals and on the cables aft of the rear rudder pedals. After removal, it could be seen that each device constituted an aluminium block, aluminium semi-circular wedge, steel cotter pin and steel retaining pin (Figure 7) with the forward devices a matching pair and the aft pair matching. Each pair was similar in construction and design however there were some minor dimensional differences.

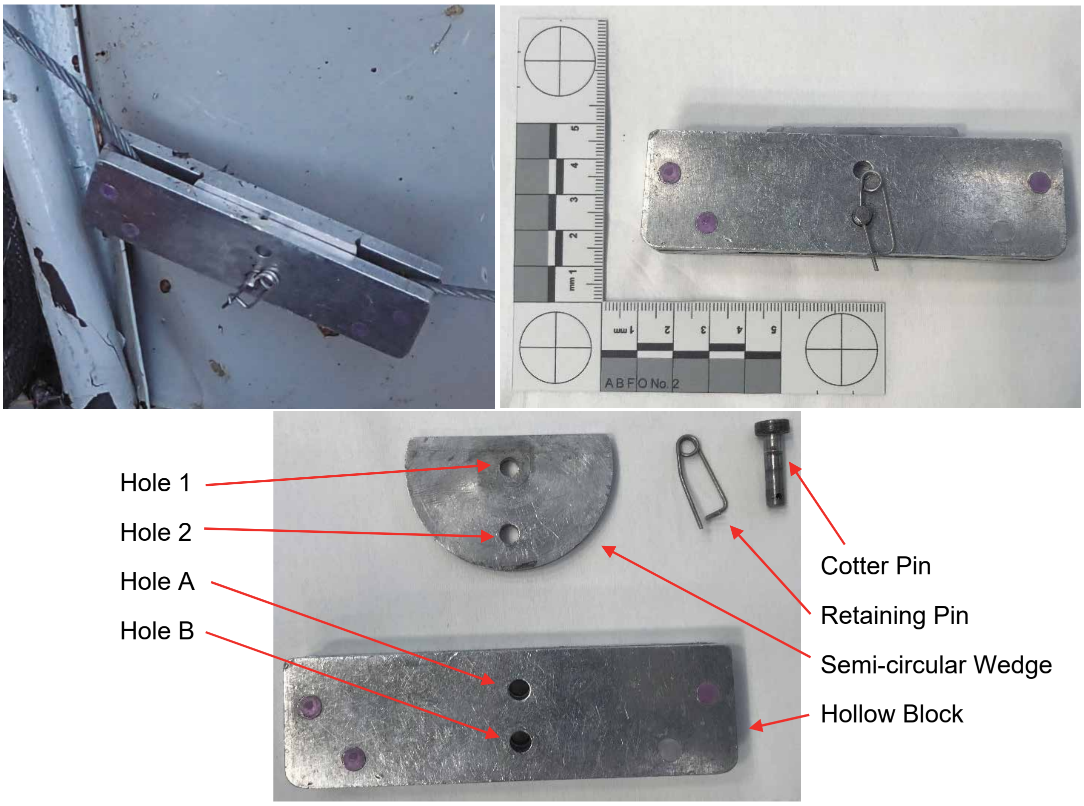

Figure 7

Rudder cable device shown in situ,
removed for examination and constituent parts

When fitted, they effectively shorten the cable by diverting it around the semi-circular wedge. In the block and the wedge, are two cotter pin holes (Figure 7) that make it possible to install the devices in different configurations. Each configuration will shorten the cable by a different amount. Table 1 shows some of the configurations and the effect they had on the rudder pedal neutral position, in terms of movement towards the seat. The aircraft was in configuration B2+B2 for the accident flight.

Device Settings		Rudder Pedal Movement	
Front	**Rear**	**Front**	**Rear**
A2	Not fitted	3 mm	None
B2	Not fitted	11 mm	None
A1	Not fitted	25 mm	None
B2	**B2**	**33 mm**	**22 mm**
Not fitted	A2	6 mm	6 mm
Not fitted	B2	22 mm	22 mm
Not fitted	A1	34 mm	34 mm

Table 1

Effect on rudder pedal movement in various device configurations

With only the front devices fitted, the front rudder pedals move aft by 3, 11 and 25 mm for the configurations shown and there is no movement of the rear pedals. When only the rear devices are fitted, both sets of pedals move by 6, 22 and 34 mm. With the devices set as they were on the accident flight, the front pedals were 33 mm aft from their nominal position and the rear pedals were 22 mm aft. This cumulative effect on the front pedals is because the rear devices also affect the front rudder pedals due to the cable layout.

A change of more than 30 mm in the front pedal neutral position when using the devices, caused the retreating pedal to come into contact with the end of the heel tray cut-out, thus preventing full pedal and rudder deflection. In the accident flight configuration (B2+B2), this interference restricted rudder movement by 3° (ie reduced the rudder movement from +/- 30° to +/-27°) and the maximum device setting restricted the rudder by 10° (from +/- 30° to +/-20°). In April 2019, the aircraft had a 50-hour maintenance check and, during the check, the devices were found already fitted to the rudder cables. While inspecting the rudder travel, the engineer noticed that there was a 6 mm gap between the rudder lever and the fuselage stop when the pedals were at the limit of their travel. This 6 mm gap at the rudder stop equated to approximately 3° of rudder travel. The devices were removed, and it was noted in the maintenance documentation that '*Non-approved rudder cable devices found fitted. Once removed rudder travel then is satisfactory*'. There was no discussion about this note between the operator and the maintenance organisation.

The fitting of these devices to the aircraft changes the definition of the rudder system as specified in the aircraft type design documentation submitted at the time of certification. The Certification of Airworthiness for G-ODDS was issued by EASA and the installation of these devices should have been achieved by an approved design change to the type design in accordance with EASA part 21.A.91 '*Classification of changes to type design*'[5]. The AAIB was unable to find an approved modification for the fitting of these devices to the aircraft rudder cables, and the aircraft manufacturer confirmed that there was no such modification or Supplemental Type Certificate modification.

The designer of the devices, a pilot and professional aeronautical engineer, stated that the devices were to allow for adjustment of the rudder pedals when using the aircraft for teaching students of different stature. It is understood that the devices were fitted and removed depending upon which pilot was flying; the commander always used them, but another pilot stated that he never used them. Their installation or removal was not recorded in the aircraft's technical logbook. The designer also stated that only the two sets fitted to G-ODDS were made. He explained that an alternative to moving the rudder pedals would be to use extra cushions between the pilot and the seat back, but this moves the pilot forward and can restrict the amount of aft control column movement and therefore the ability to pitch the aircraft up. He further stated that, in his opinion, they were "personal role equipment" and as such did not require a modification. It should be noted that these devices had been used in G-ODDS by many pilots over many years, in training and competition flying, without incident.

Footnote

5 https://www.easa.europa.eu/acceptable-means-compliance-and-guidance-material-group/part-21-airworthiness-and-environmental [Accessed 16 October 2020]

Brake pedals

The geometry of the brake master cylinder and pedal connecting linkages means that, as the rudder pedal moves towards the rear of the aircraft, the brake pedal does not move as much (Figure 8 left and middle). The brake pedal position influences the pilot's foot posture and, with soft soled shoes as both pilots were wearing, extension of the toes would result in an optimal direction of force applied to the rudder pedal (Figure 8 right) with minimal force applied to the brake pedal. However, it has been stated that, whilst flying aerobatic manoeuvres, it is not uncommon for pilots to inadvertently apply the wheel brakes. Despite this small application of the brakes, the main application of force is through the rudder pedal.

Figure 8

Rudder / brake pedal relative movement and foot posture

Aircraft performance

The aircraft manufacturer was asked to provide information regarding flight characteristics in a spin. The manufacturer stated that the aircraft has no adverse spinning characteristics and that it is cleared for upright, inverted and accelerated spinning. The investigation spoke to a number of pilots whose experience was that the spin characteristics of the Pitts were predictable.

Spin characteristics

Spin characteristics vary significantly depending on pilot inputs so, to determine performance in a spin, the assumption was made that a conventional technique to induce and maintain a spin was used, ie full rudder and control column held fully back with ailerons neutral. Information provided by the manufacturer indicated that a 10-turn upright spin incurred a height loss of 3,400 ft in an elapsed time of 32 seconds. Therefore, each spin rotation takes approximately three seconds and incurs a loss of 340 ft with a rate of descent of approximately 6,800 fpm.

The manufacturer advised that, with full opposite rudder deflection and neutral (or released) control column, it would take approximately 500 ft to stop the rotation and then another 500 ft to level flight with a 4 g acceleration.

It is not possible to determine what control inputs were made during the spins on the accident flight but deviations from the conventional technique outlined above would affect spin rate, rate of descent and time for recovery. The ground marks were consistent with a right-hand upright spin and the following information, provided by a test pilot, indicates how the spin may vary if the controls are not held in the conventional pro-spin positions:

a. Increased power would have an anti-spin effect and could be expected to lower the pitch attitude, increase the spin rotation rate and reduce the number of turns and time to recover.

b. Left or out-spin aileron would have a pro-spin effect which would result in a flatter, more wings-level spin and possibly a higher spin rotation rate. Even if the ailerons were set to neutral during the recovery, the number of turns and time to recover would both increase, compared to a neutral aileron spin. If out-spin aileron was maintained during the recovery, the pro-spin effect could overpower the anti-spin effect of the recovery rudder and the aircraft may not recover.

c. Right or in-spin aileron would have an anti-spin effect which could result in a steeper nose-down spin. If the ailerons were then set to neutral during the recovery, the aircraft would recover from the spin in fewer turns and less time than from a neutral aileron spin. However, if in-spin aileron was maintained during the recovery the aircraft could potentially enter another spin, possibly inverted, in the opposite direction.

d. If the rudder remained fully deflected in the direction of the spin it would be highly unlikely for the aircraft to recover from the spin irrespective of the aileron and elevator positions.

The manufacturer supplied the investigation with a flight test report for spinning. The flight test was conducted in 1971 at the maximum takeoff weight and with a C of G position 97.7 inches aft of the datum. The aircraft entered left and right-hand spins using conventional pro-spin controls. Using a conventional recovery technique, the aircraft stopped the rotation to the right in one half turn and in one turn from a spin to the left. When the controls were released during a spin, the aircraft recovered by itself within one and a half turns. When aileron was applied in the opposite direction to the spin, the spin became flatter. Ailerons were then neutralised, and, with the conventional recovery technique, the spin stopped in less than three rotations.

The test pilot also advised that:

'In a spin, a pilot will experience multiple visual, rate and acceleration cues about multiple axes, and the motions may be steady or oscillatory. The body is more sensitive to some of these cues than to others and, therefore, the perception of the motion may not be representative of the actual motion of the aircraft. In particular, conflicting acceleration and visual cues can cause marked disorientation. Roll direction is a very powerful visual cue if a good horizon is present. However, yaw (and hence spin) direction may be wrongly identified due to visual cues possibly being blurred at high yaw rates plus variations in

yaw rate causing sensory confusion (analogous to being on a swivel chair and stopping suddenly). There can also be an unconscious perception of spin direction driven by the roll direction, especially if roll direction changes. Overall, the best single and simple cue to ascertaining spin direction is to interpret the turn needle.'

G-ODDS had a turn indicator fitted in the front cockpit but not in the rear. Both cockpits were fitted with a slip indicator[6].

Weight and Balance

The aircraft departed White Waltham with 64 litres of fuel on board. This was the operator's standard fuel load for aerobatic sorties. A climb to an altitude of 3,500 ft and transit to the area of the accident would use approximately 11 litres of fuel and take under 10 minutes.

The operator had created a spreadsheet to calculate aircraft weight and C of G position. A copy of the spreadsheet was obtained from the commander's computer. The total aircraft weight used in that copy was 1,097 lb and a C of G position 88.00 inches aft of the datum. The operator stated that the figures '*were supplied with the aircraft and were in the tech log at the time of purchase*'. These figures came from weighing the aircraft in 2005.

Following the fitting of a new propeller, the aircraft was reweighed in 2007 and its mass had increased to 1,124 lb and the C of G position had moved further aft to 89.79 inches aft of datum. The operator stated they were unaware of the most recent weight report at the time of the accident and only found the most recent weight and balance report after the event. In addition, the pilots' weights used in the calculations were significantly less than their actual weights; the commander's weight was underestimated by 6.35 kg (14 lb) and the student's weight by 9.98 kg (22 lb). The source of these figures is unknown. A copy of the Weight and Balance calculation believed to have been used by the commander prior to the accident flight is shown in Figure 9. The numerals on the blue line corresponds to a range of possible fuel quantities in litres.

The use of incorrect figures could have misled the commander into thinking that the aircraft was within its flight envelope for the planned sortie. Figure 10 shows a more accurate result with figures from the most recent weight and balance report. The actual pilot weights, the weights of the additional seat cushions and the miscellaneous equipment found in the aft cockpit locker have also been included.

Footnote

[6] A turn indicator is used to indicate the rate at which the aircraft changes heading. The instrument is helpful whilst in a spin, as it indicates the direction of yaw. The slip indicator shows whether corrective rudder is required to achieve balanced flight.

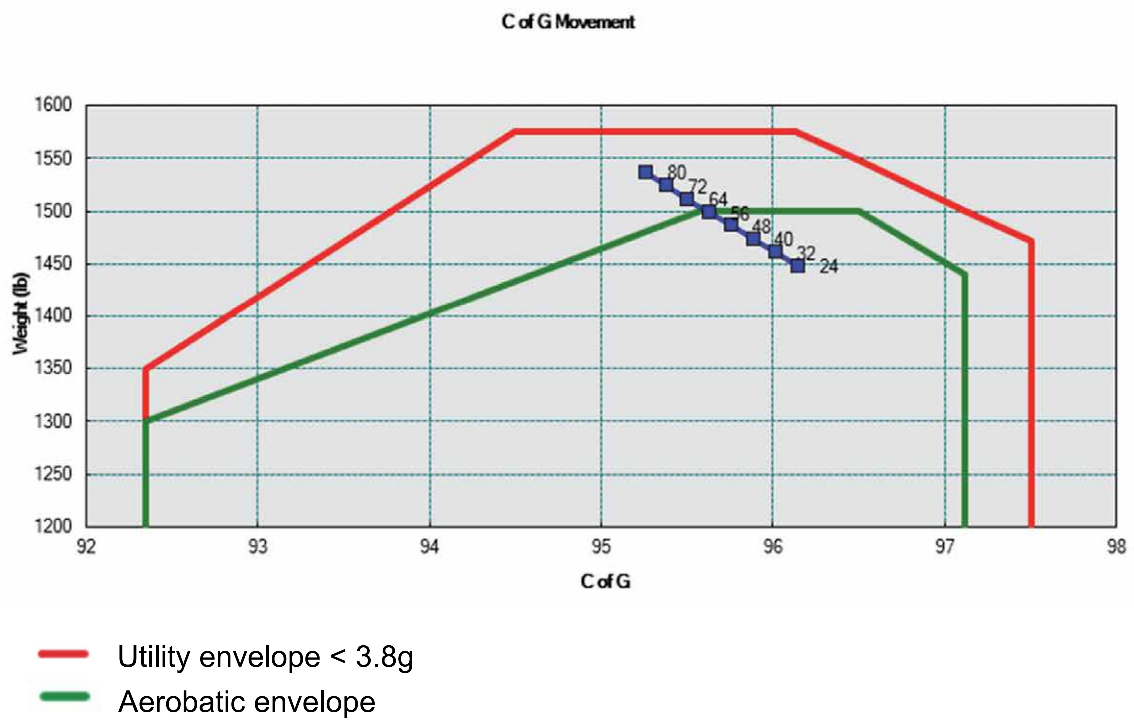

Figure 9

Commander's Weight and Balance spreadsheet

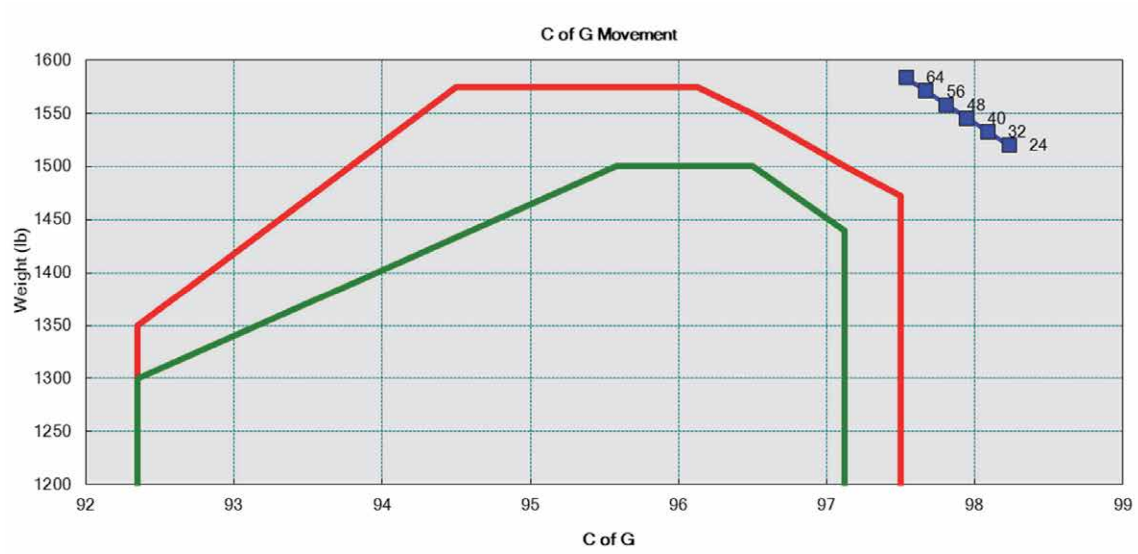

Figure 10

Revised Weight and Balance spreadsheet

With these figures the aircraft was overloaded for both the aerobatic and utility flight envelopes. The most rearward C of G limit for aerobatics is 96.5 inches at a gross weight of 1,500 lb increasing to 97.12 inches at 1,440 lb. For the utility category the limits are 96.13 inches at 1,575 lb increasing to 97.5 inches at 1,472 lb. The aircraft manufacturer stated that the overload condition would not have affected the aircraft's capacity to recover from a spin. Having been advised that, at the time of the accident, G-ODDS's C of G position was further aft than the limit, the manufacturer stated that:

> *'The AFT C.G. limit is the aft most point that the aircraft should be operated in. This data was the direct result of FAA flight testing during certification that resulted in the limits depicted in the flight manual.'*

Movement of the position of the C of G affects the positive longitudinal stability of the aircraft and it also affects the handling characteristics in pitch. If the C of G is moved aft, outside the permitted limits, the positive stability of the aircraft in pitch is reduced and the reduction in the moment arm of the rudder and elevators reduces their effectiveness. The flight test report referred to earlier, stated that the C of G used for the test was 97.7 inches.

Survivability

Neither pilot wore a parachute so abandoning the aircraft was not an option. The forces exerted on both pilots during the impact resulted in injuries that were not survivable. Despite the high impact forces, the fuselage remained largely intact and the cockpit spaces were preserved. However, it was noted that the rear cockpit seat, along with its seat belts, had detached from the airframe. The front cockpit seat was still attached but despite wearing a five-point harness, the occupant sustained severe facial injuries through impact with the edge of the cockpit.

Organisational information

The operator specialises in aerobatic, formation flying and vintage aircraft training. It also provides private flying displays and conducts event days for corporate clients.

The operator stated that they wrote to all students prior to the start of their training to indicate that 89 kg was the maximum acceptable weight for pilots. The Skyway Code (CAP1535) contains extensive information on aircraft mass, balance and performance. Of note it states:

> *'Account for everything – when adding up the mass of the aircraft make sure you account for all items onboard. Miscellaneous things such as bags should be included in whichever loading point they are closest to.*
>
> *Passenger mass – ensure you know the mass of your passengers, including clothing and other accessories they may be carrying.'*

Aerobatic training

The operator did not have standardised sortie plans for aerobatic instruction, with sortie content decided for each individual student by each individual instructor. The objective was to prepare pilots for the Sport level of aerobatic competition. For spin recovery, the operator taught the Beggs/Mueller method, which is as follows:

- Power to idle.
- Release the control column.
- Apply full opposite rudder until rotation stops.
- Neutralise rudder and recover to level flight.

The advantage of this method is that it works for either an upright or inverted spin and so reduces the likelihood of a disorientated pilot taking incorrect actions.

AOPA Syllabus

The operator stated that the commander, when instructing, '*would invariably follow the AOPA Standard Course Syllabus*'. The AOPA syllabus states '*Recoveries from all manoeuvres must be completed by a minimum of 1000 feet above the surface, and a maximum height must also be observed of 500 feet below the base of regulated airspace. Greater margins are likely to be wise until adequate experience has been gained*.' The operator stated that the 500 ft below regulated airspace, specified in the AOPA syllabus, was not considered as a standard operating procedure. For Sport level aerobatics, the base height is 1,000 ft agl and there is no upper limit in the British Aerobatic Association Rules.

Pre-flight briefing

The operator used a generic briefing outline from another organisation. It consisted of '*Aim, Briefing, Air Exercise*' followed by '*Threat and Error Management*'. The actual content was decided for each sortie and student. A pre-flight briefing is an opportunity to address issues, such as a loss of communication, but it is not known if these were discussed by the crew. The operator stated that the commander habitually gave thorough pre-flight briefings and believed that contingencies were routinely covered.

Parachutes

The operator had parachutes available and stated that pilots are given the option of wearing one. However, the operator also stated that '*the weight of the parachutes increases the cockpit weights significantly, and therefore operate to limit the aircraft's operational weight and balance capability*.' Neither pilot involved was wearing a parachute.

Other training organisations

The investigation contacted another training organisation which advised that it provides a standard briefing for commanders to cover eventualities such as loss of communication, abandoning the aircraft and the initiation of recovery actions. However, that organisation requires the use of parachutes and so the briefing text reflects their use in abandoning an aircraft in an emergency. The briefing does address the issue of loss of communication between the pilots but, as it uses aircraft with side-by-side seating, not all of the briefing is appropriate or relevant to the accident aircraft.

That operator uses a Minimum Abandon Height (MAH) of 3,000 ft agl. An allowance of 2,000 ft is made for recovery so the minimum height to commence recovery would be 5,000 ft agl. A further allowance of 400 ft per turn is added to derive an entry height. Therefore, using a four turn spin as an example, the minimum height for spin entry would be 6,600 ft agl or, in the vicinity of the accident site, 7,100 ft amsl and provides for significant safety margins in terms of altitude.

Tests and research

A specialist anthropometrics consultancy service was engaged to assist in understanding the effect that the rudder cable devices and the extra seat cushions might have had on the controllability of the aircraft. The consultants were supplied with a digital representation of an exemplar aircraft and used measurements of the pilots to construct digital mannikins. In this digital environment they assessed the pilots' ability to operate the controls through their full range of movement.

To construct a digital representation of the G-ODDS airframe, another Pitts S-2A airframe of the same build standard was scanned using the GOM structured light scanning system[7] (Figure 11). An SAE H-point machine[8] was placed in the cockpit (Figure 12) and scanned to fix the key datums and enable positioning of the pilot mannikins in the digital environment. The consultants were also able to observe a pilot in the cockpit who was familiar with flying the Pitts Special to gain an understanding of posture and position when flying.

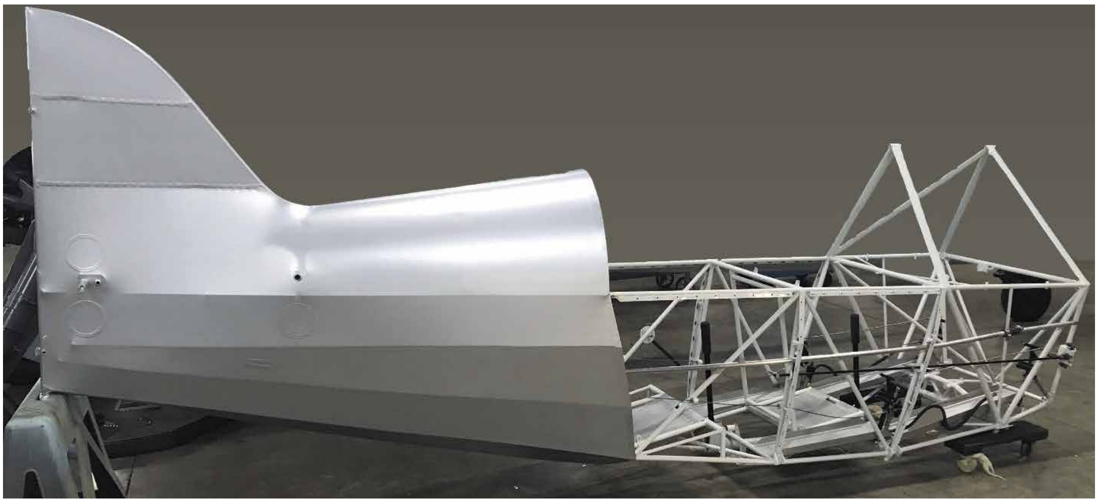

Figure 11

Representative airframe ready to be GOM scanned

Footnote

7 https://www.gom.com/metrology-systems/atos/atos-triple-scan.html [Accessed 16 October 2020]
8 https://www.sae.org/standards/content/j4002_200508/ [Accessed 16 October 2020]

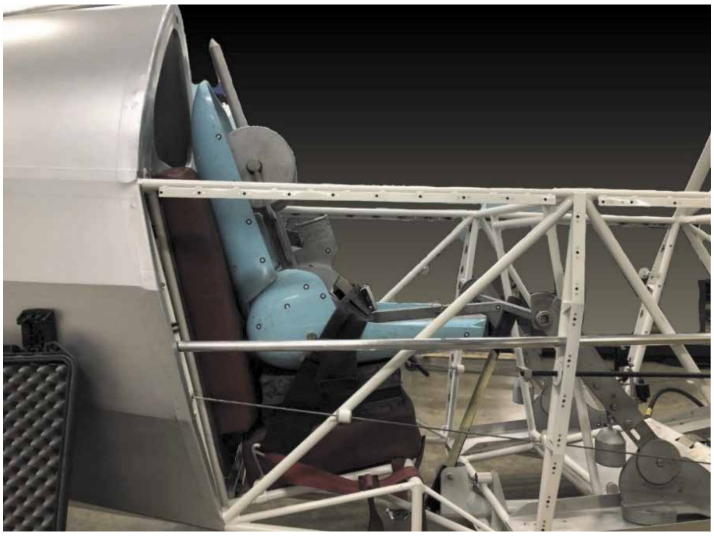

Figure 12
SAE H-point machine installed in the rear cockpit

Where required body dimensions were not available, the anthropometric consultants estimated figures based on other known proportions and photographs[9]. The measurement data was then imported into the System for Aiding Man Machine Interaction Evaluation (SAMMIE) Digital Human Modelling software tool and a digital mannikin was created for each pilot. Using the scanned digital cockpit environment and the H-point machine, the SAMMIE digital mannikins were then positioned in the cockpit and the Seating Reference Points (SgRP) were defined (Figure 13).

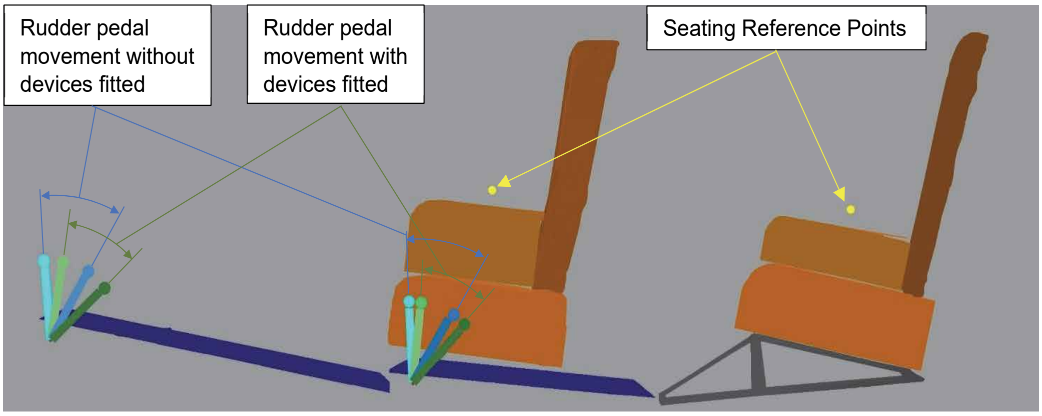

Figure 13
SgRPs and rudder pedal movement

Footnote

[9] Human body dimensions are usually described in terms of percentiles which show where a measurement lies within the distribution of that measurement for the population of interest. For example, stature may be expressed as 5th percentile UK male which means that 5% of the population are smaller than this value and 95% of the population are taller. The same convention can be used for any body dimension and those that were estimated were based on the same percentile as the stature of the pilots. This is a simplification because bodies vary, and people can have relatively larger or smaller individual body dimensions than would be expected if all were exactly in proportion to their stature.

An assessment was made of the ability of each pilot to achieve full rudder pedal deflection without any rudder cable devices fitted and with the devices installed as per the configuration used during the accident flight. Figure 14 shows the digital mannikins located on the SgRPs and positioned for full forward travel of the right rudder pedal without any devices fitted.

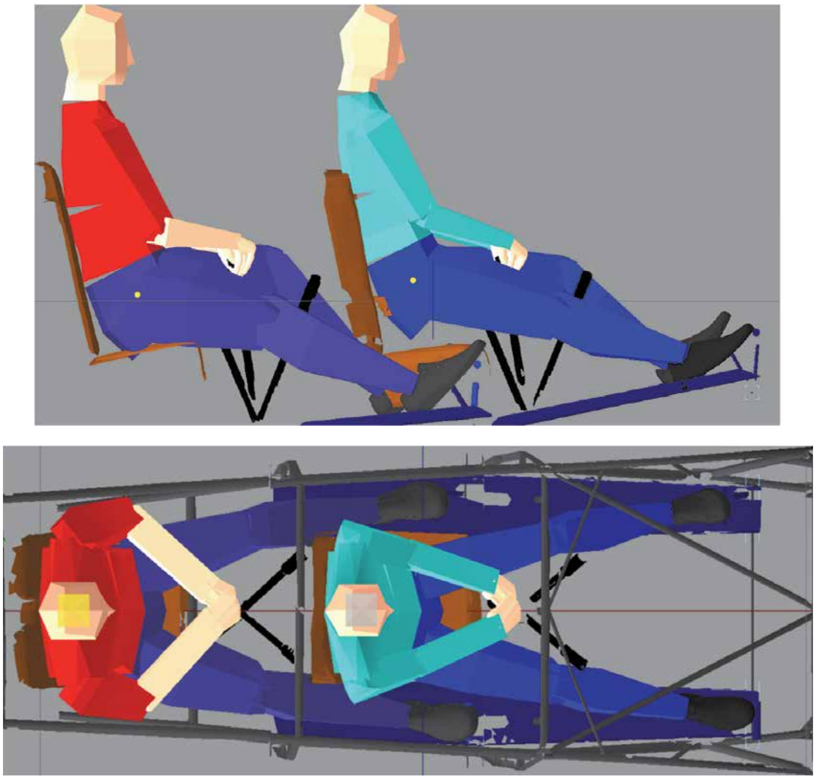

Figure 14

Right rudder pedals full forward without the devices fitted
(brake pedals omitted for clarity)

The assessment showed that the commander was unlikely to have been able to move the pedal to this position because the leg is fully extended with only the tip of the toes in contact with the pedal. The student was likely to have had better foot contact on the pedal and the leg is only slightly bent, but this position may have been uncomfortable due to the additional seat cushions digging into the thigh and the front seat back on the inside of the calves. The assessment showed that the receding pedal position was unlikely to pose a problem for either pilot to exert the force necessary to return the rudder to the neutral position.

With the devices fitted as they were on the accident flight (Figure 15), the assessment showed that the commander would be able to reach the extreme of pedal travel more easily. Full extension of their leg was still required but instead of the toe, the ball of their foot would likely have been on the pedal affording more control.

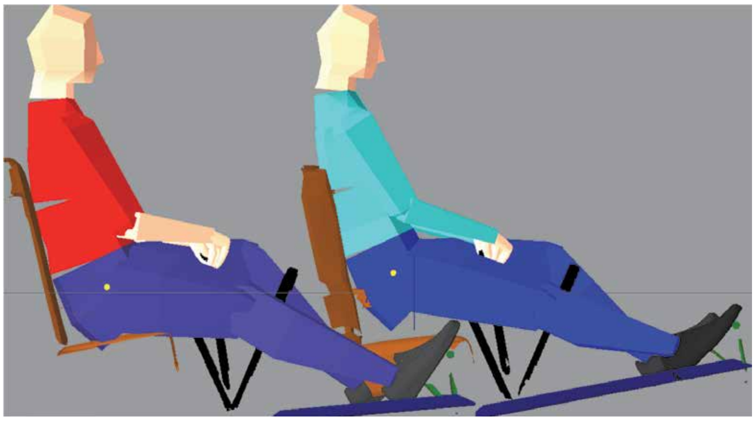

Figure 15
Right rudder pedals fully forward with the devices fitted
(brake pedals omitted for clarity)

Further assessment of this configuration suggested that it would probably have been more comfortable for the student because of the increased bend in the leg. It would also reduce the pressure of the seat cushion on the back on the thighs and allow an improved position for the calves around the front seat back.

The investigation considered the scenario that the commander had become incapacitated during the spin manoeuvre and so could have impeded the recovery of the aircraft. It was assumed that the spin was entered using full right rudder (and control column held fully back with ailerons neutral) and the commander would have a fully extended right leg on the rudder pedal when they became incapacitated. Spin recovery would require the student to apply full opposite (left) rudder.

Digital modelling and practical assessment of this scenario was made using the SAMMIE tool and an exemplar aircraft and it was found that it was possible to apply the required rudder input even against a 'locked' straight leg. The commander's joint mobility was explored via digital modelling (Figure 16) and although the ankle is nearing the limits of extreme movement, it is possible for full opposite rudder to be applied. Typically, an external force would be required to extend the ankle to this position but a further 6° of extension is possible in the extreme range.

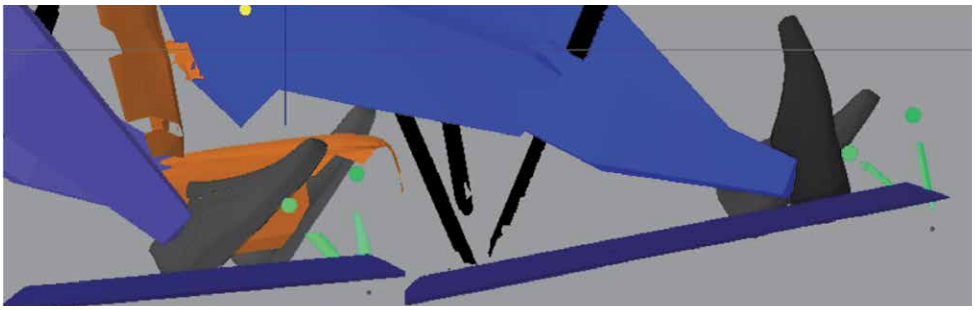

Figure 16
Commander ankle movement with full opposite rudder
(brake pedals omitted for clarity)

Analysis

Introduction

From the limited evidence available, it is likely that the commander of the aircraft became incapacitated in flight, probably at the start of, or during, the second spin sequence that was observed by witnesses. Ground impact marks indicate that the aircraft was still in a spin as it struck the ground and there was no indication of successful recovery action.

Both pilots had been trained in spin recovery and so if the controls were not restricted, they had the skills and knowledge necessary to affect a safe recovery. As there was a qualified pilot in the rear seat, the investigation considered the reasons why the student did not, or was unable to, recover the aircraft to level flight with the commander incapacitated.

Control restrictions, reaction to a loss of communication between commander and student, and the time available to recover to level flight are discussed in further detail below. Pre-flight planning is also discussed.

Rudder/elevator damage

It is considered that, at the time of impact, the rudder was in the neutral position or towards the right. The contact damage on the left side of the rudder and the deformation to the left elevator would require a significant impact force. The left rudder stop was intact, and, after the accident, it was not possible to move the rudder far enough to touch the elevator, therefore the rudder must have deformed. The lightweight rudder is stiff, and it would need a lot of momentum to deform significantly which could not be achieved if the rudder was against the left stop. If the pedals were holding the rudder neutrally or to the right, it is still possible for the rudder to move. As the fuselage deformed during the impact, the bending would have released the tension in the rudder cables, thereby allowing free movement of the rudder.

Pre-flight preparation – discussion

The content of the pre-flight briefing is unknown so it cannot be confirmed what was discussed with regard to actions for loss of communications and definition of recovery altitudes. Discussion of such actions in pre-flight briefings could, in general, assist in reducing the effect of any surprise or distraction that students may suffer. It may also encourage prompt action at a time when sufficient height remains to carry out a recovery.

Area of operation

The area of the accident was approximately 8 miles from White Waltham and although constrained above by the London TMA, offered more altitude than would be required for competition aerobatic manoeuvres. Slightly further north, the base of controlled airspace increases to 5,500 ft amsl although it is constrained laterally by the RAF Benson Military Aerodrome Traffic Zone. A transit flight of 20 nm would have taken the aircraft to an area where the base of controlled airspace is 8,500 amsl. Based on the albeit erroneous weight and balance calculated figures which limited the fuel load available, the commander may have chosen the accident locale to maximise aerobatic training time.

Weight and Balance

The aircraft departed with 64 litres of fuel which was a standard load intended to ensure that the aircraft was within its C of G envelope. As each of the operator's instructors had an idea of the limitations because of their own weight, it was not usual for them to calculate the exact C of G prior to each flight. The operator had created a spreadsheet to automate the C of G calculations, which calculated the mass and balance for a range of fuel loads. Figures obtained from the commander's computer showed a calculation with incorrect weights for both the pilots and the aircraft. Using the accurate weights, the aircraft was overloaded, and the C of G was further aft than both the published limit and the 97.7 C of G position in the flight test report. The aircraft manufacturer did not consider that the overloading would have impeded any spin recovery. However, the aft C of G position would have reduced the moment arm of the rudder and elevator controls, making a recovery more difficult.

Spinning

Once in a spin the aircraft descends at approximately 6,800 fpm. Directly above the accident site, the base of controlled airspace was 3,000 ft agl. Had the aircraft entered the spin at this height, a maximum of approximately 26 seconds would have been available before the aircraft would have struck the ground. If the commander had considered that the aircraft was clear of the lower band of controlled airspace and entered a spin at 5,000 ft agl, a maximum of approximately 44 seconds would have been available. If the commander had followed the AOPA guidance to remain 500 ft clear of controlled airspace these maximum times would be reduced by approximately four seconds.

From 3,000 ft agl, with 500 ft needed to arrest rotation and 500 ft to level, spin recovery would have needed to be initiated within 17 seconds to just avoid contacting the ground. From 5,000 ft agl, a maximum of 35 seconds would have been available. The durations are a maximum and make no allowance for a planned number of turns before recovery action is initiated. It is not known what manoeuvres or how many turns of spin were planned.

Incapacitation

The commander had, unknowingly, a serious cardiac condition, with the potential to cause incapacitation with little or no warning symptoms. The coronary pathology indicated that, while the condition would have taken months or indeed years to develop, it could have been completely asymptomatic. Even had the commander undergone a recent ECG, it would have been difficult to detect the condition due to the inherent circulation reserves of the cardiac tissues. Only a 'stress test' ECG such as that conducted during physical exercise to elevate the heart rate is likely to have revealed the condition.

Student response

The student had an aerobatic rating. The training for this included spinning and spin recovery, and so the student would have had the skills and knowledge to recover from a spin. Had the aircraft entered a spin from 3,000 ft agl, the student would have had a maximum of 17 seconds in which to initiate recovery actions from commencement of the spinning manoeuvre. This would be enough time for an appropriately trained pilot to take corrective action unless impeded by another factor.

Following the likely incapacitation of the commander, the student either did not attempt to recover the aircraft in time or tried but was unable to do so. It is possible that a physical control restriction impeded or prevented the student from taking recovery action, but this is considered unlikely.

If recovery was physically possible, then there may have been circumstances that reduced the time available for the student to recover, or his ability to do so. Apart from the eyewitness accounts and radar recording, there was no evidence to inform the investigation about the exercise being flown or any of the interactions between the commander and student. The following discussion outlines some plausible scenarios.

The Pitts Special has tandem cockpits so the student's view of the commander would have been restricted and communication between the two of them relied on intercom. If the student was awaiting an instruction from the commander to recover from the spin it is likely that their recognition of the situation would have been delayed. If the student thought communication had been lost, it is probable that attempts to re-establish communication with the commander would have been made to ascertain if there was a problem. If recognition of the need to act took too long, or too much of the limited time available was spent trying to re-establish communication, it could account for why the aircraft was still spinning at impact. There may also have been factors that impaired the student's ability to respond in the event that the commander was incapacitated during the spinning; the situation in the aircraft could have caused startle, surprise, confusion or panic and the motion of the aircraft may have caused disorientation. If the student was disorientated, they could have misidentified the yaw direction and it is possible they could have maintained or applied right rudder believing that it was the appropriate corrective action. Reference to a turn indicator, such as was fitted in the front cockpit only, would have helped to counter disorientation in a spin. Any one or combination of these factors could have reduced the student's ability to make a recovery in the limited time available.

Rudder cable devices

G-ODDS had been used as a school and competition aircraft for many years and had been flown by a lot of different pilots of varying stature and build. The design of the cockpit of the Pitts Special does not allow for personalised adjustment of the flight controls, specifically the rudder pedals, and so some devices had been designed and constructed for use in G-ODDS which, when installed would effectively move the rudder pedals aft. The devices enabled shorter pilots to achieve full rudder deflection without compromising the aft movement of the control column. The alternative to moving the rudder pedals aft would be move the pilot forward which, as the seat positions are fixed, would require additional seat cushions behind the pilot. This could compromise the aft movement of the control column against the pilot's torso and therefore the rudder devices could be seen by pilots to be a preferential option.

The fitting of such devices should be an EASA approved modification so that their operation and effects can be tested and documented. The investigation was unable to locate any approval for a modification to fit these devices. It was noted during a maintenance check that the devices, which were fitted at the time, restricted the rudder travel by 3° (10% of travel).

The devices allowed for a variety of settings and, in the most extreme configuration, restricted rudder movement by 10° (33% of the rudder travel). Although the investigation did not explore the effect of all the possible configurations, anecdotal evidence suggests that the devices had been used on many previous occasions without any adverse effects being reported. No records were kept detailing their installation or removal.

By building a digital representation of the cockpit environment it was possible to analyse the position of the pilots in the aircraft's fixed seats and what effect the rudder pedal devices had. Certain estimates had to be made to construct the digital representation of the pilots, but the analysis showed that, without the devices fitted, the commander, seated on a number of cushions to improve external visibility, probably would not have been able to achieve the fully-deflected rudder pedal position. Using the devices enabled the commander to do so. The student did not need to use the devices but, with them fitted, it probably would have allowed for a more comfortable position as the pedals are either side of the front seat.

Conclusion

It is likely that the commander was incapacitated by an undiagnosed cardiac condition while conducting a spinning exercise, though it is unlikely that such an incapacitation would impede the controls and prevent recovery action by the student. The evidence of the witnesses and the ground marks indicate that the aircraft was still in a spin, and both pilots were fatally injured when it struck the ground.

The rear seat student was a qualified pilot with an aerobatic rating and there was sufficient time to recover if prompt action was taken. However, a loss of communication between the pilots could have delayed recognition of the situation. The aft C of G position would have reduced the capability of the aircraft to recover from a spin and extended the time required for recovery. It is also possible that a combination of any or all of disorientation, startle, surprise, confusion or panic prevented the student from taking effective recovery actions in the limited time available.

Unapproved devices, which adjusted the rudder pedal positions, were found on the rudder cables but were unlikely to have impeded the recovery from the spin.

Safety action

Since the accident the operator has taken the following safety actions:

- The use of spreadsheets has been discontinued and Aircraft Flight Manual (AFM) weight and balance charts are used instead. A current weight and balance report is now included in the aircraft technical log.
- The operator has circulated the AFM weight and balance charts together with current weight and balance reports to all instructors.
- Scales are now provided so pilots can weigh themselves. The operator has found large discrepancies between given and actual weights among its pilots and no longer accepts assumed or estimated weights.

- The operator has encouraged pilots and instructors to continue to take notice of weight and balance placards in the aircraft, which require confirmation that the weight and balance has been checked before flight.
- Electronic copies of flight manuals have been circulated to all instructors (and are available for students) to provide reference material on weight and balance.

Published: 21 January 2021.

Bulletin Correction

The report first published on 21 January 2021, contained the sentence on page 11:

> In April 2019, the aircraft had a 50-hour maintenance check and the devices were fitted to the cables during the check.

To provide clarity that it was not the maintenance organisation that fitted the devices, this sentence has been changed to:

> In April 2019, the aircraft had a 50-hour maintenance check and, during the check, the devices were found already fitted to the rudder cables.

The online version of this report was corrected on 28 January 2021.