

List of Aircraft Accident Reports issued by AIB in 1975

No.	Short title	Date of publication
1175	Boeing 737-200 (G-BAEF) at Luton Airport, Beds. March 1974	October 1975
1275	Douglas DC7CJL EI-AWG at Luton Airport, Beds. March 1974	October 1975
1173	Vickers Vanguard 522 G-AXOP at Hodwood, Solihull, Warwickshire. April 1975	September 1975
1075	Piper Twin Commander PA30 G-ATYK at Sullane Bay, near North Canal aerodrome, Aryll, October 1974	November 1975
9175	Piper PA15-235 G-ASVX and Phantom FG93 XN493 at Farnham Fen, Norfolk. August 1974	September 1975
8175	Cessna 150C G-ASHF at Swanage Bay, Dorset. June 1973	August 1975
7175	Ibora DCP EC-B11 and Searox Colorado EC-B1C in the Nantes area, France. March 1973	June 1975
6175	Bell 206A Jet Ranger G-AKAY at Jackson Hill, Hungerford, Berks. March 1974	July 1975
5175	at Gange Farm, Lalehampton, Wiltshire, 15th April 1974	June 1975
4175	at Farnborough, Hampshire. April 1974	June 1975
3175	Piper PA-23 Series 130 (A130) G-AYDF and BAC 111 Type 318 G-AZML at Luton Airport, Beds. April 1974	June 1975
2175	Airfield 2 at Yarnfield, January 1975	May 1975
1175	Westland Sea King MK 41 G-361 at Yeovil Airfield, 2 January 1975	May 1975
1	Boeing 737-200 (BARON) G-AZXL at Cheshambury cum St. Leonards, Bucks. January 1974	May 1975

Department of Trade

ACCIDENTS INVESTIGATION BRANCH

**Sikorsky S-67 Blackhawk N671SA  
Report on the accident at Farnborough,  
Hampshire, England, 1 September 1974**

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<i>No.</i>	<i>Short title</i>	<i>Date of publication</i>
1/75	Beechcraft 95-B55 (BARON) G-AZZJ at Cholesbury cum St. Leonards, Bucks January 1974	May 1975
2/75	Westland Sea King MK 41 89-61 at Yeovil Airfield, Somerset January 1974	May 1975
3/75	Piper PA-23 Series 250 (Aztec) G-AYDE and BAC 111 Type 518 G-AXMJ at Luton Airport, Beds April 1974	June 1975
4/75	Boeing 707-436 G-APFH at Heraklion Airport, Crete June 1974	June 1975
5/75	Rollason Druine D31 (Turbulent) G-APLZ at Grange Farm, Latchington, Maldon, Essex April 1974	June 1975
6/75	Bell 206A Jet Ranger G-AXAY at Inkpen Hill Hungerford, Berks. March 1974	July 1975
7/75	Iberia DC9 EC-B11 and Spantax Coronado EC-BJC in the Nantes area, France March 1973	June 1975
8/75	Cessna 150C G-ASHF at Swanage Bay, Dorset June 1973	August 1975
9/75	Piper PA25-235 G-ASVX and Phantom FGR2 XV493 at Fordham Fen, Norfolk August 1974	September 1975
10/75	Piper Twin Comanche PA30 G-ATYR at Saulmore Bay, near North Connel aerodrome, Argyll October 1974	November 1975
11/75	Vickers Vanguard 952, G-AXOP at Hochwald/Solothurn, Switzerland April 1973	September 1975
12/75	Douglas DC7C/L E1-AWG at Luton Airport, Beds March 1974	October 1975
13/75	Boeing 727 Series 46 G-BAEF at Luton Airport, Beds June 1974	October 1975

<i>No.</i>	<i>Short title</i>	<i>Date of publication</i>
14/75	Boeing 747 136 G-AWNJ near Nairobi Airport, Kenya September 1974	January 1976
15/75	Piper PA 31-350 Navajo Chieftain G-BBJG at Horsforth, Leeds, Yorks December 1974	January 1976



Department of Trade  
Accidents Investigation Branch  
Shell Mex House  
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30 January 1976

*The Rt Honourable Peter Shore MP  
Secretary of State for Trade*

*The Rt Honourable Roy Mason MP  
Secretary of State for Defence*

Sir,

I have the honour to submit the report by Mr G C Wilkinson, an Inspector of Accidents, on the circumstances of the accident to Sikorsky S-67 Blackhawk N671SA which occurred at Farnborough Aerodrome, Hampshire, England on 1 September 1974.

I have the honour to be  
Sir  
Your obedient Servant

W H Tench  
*Chief Inspector of Accidents*



Accidents Investigation Branch  
Aircraft Accident Report No 1/76  
(EW/E17)

*Aircraft:* Sikorsky S-67 Blackhawk N671 SA  
*Engines:* Two General Electric CT 58-140-2  
*Registered Owner and Operator:* Sikorsky Aircraft Division, United Aircraft Corporation, USA  
*Crew:* Commander – Died of injuries  
Co-pilot – Killed  
*Passengers:* None  
*Place of Accident:* Farnborough Aerodrome, Hampshire, England  
51° 17'N 00° 46'W  
*Date and Time:* 1 September 1974 at 1553 hrs  
All times in this report are GMT

## Summary

The Sikorsky S-67 Blackhawk was carrying out a demonstration at the press preview of the Society of British Aerospace Companies (SBAC) 1974 Farnborough Air Show. Towards the end of its planned display the Blackhawk carried out a low level roll to the right starting at a height of 300 to 400 feet and then almost immediately started a second right hand roll. Whilst the helicopter was inverted the nose fell below the horizon and it then executed a manoeuvre mainly in the looping plane in an apparent attempt to recover. However, although it achieved a level attitude the helicopter struck the ground with a high rate of descent and caught fire. The co-pilot was killed in the crash and the commander died nine days later.

The report concludes that the accident was caused by the failure of the commander to establish the correct entry conditions for a low level roll manoeuvre and that under these circumstances the height at which the manoeuvre was started was inadequate to permit recovery.

# 1. Investigation

## 1.1 History of the flight

Blackhawk S-67 N671SA arrived from the USA at RAF Woodbridge, a United States Air Force base in East Anglia, on Monday 26 August 1974 to carry out a work-up programme with a Sikorsky CH-53 for a Sikorsky Aircraft co-ordinated display at the SBAC Farnborough Air Show. Practices were flown at Woodbridge on Tuesday 27 and Wednesday 28 August. These practices included rolls by both the CH-53 and the Blackhawk, the latter being flown throughout by the crew who flew the aircraft at Farnborough.

The Blackhawk has carried out hundred of rolls, all to the right, during its life. These rolls were always carried out with the Stability Augmentation System (SAS) and the roll channel of the Feel Augmentation System (FAS) selected out. The pitch channel of the FAS is normally selected in for display flying, including rolls, but is not considered by Sikorsky to be essential.

As part of the display worked up at Woodbridge the Blackhawk practiced a roll to the right through 360° initiated at about 300 to 400 feet followed, after an acceleration period of approximately 10 to 15 seconds in order to restore IAS, by a second roll to the right which was stopped after 270° so as to enter a steep turn to the left. On Thursday 29 August the two aircraft flew to Farnborough and carried out a five minute co-ordinated display rehearsal during which this double roll manoeuvre was satisfactorily executed parallel to the main runway, along a display line of 'dayglo' markers. This display was watched by members of the SBAC Flying Control Committee as well as by the Sikorsky ground crew. The committee members were satisfied the display was safe, the Blackhawk's rolls being carried out at about 500 feet without loss of height and with an ample time elapsing between the two rolls.

On Sunday 1 September the Sikorsky aircraft were scheduled to take part in the press day preview of the show. The Blackhawk was reported to be fully serviceable prior to start-up but the CH-53 pilot stated that after the start-up the commander of the Blackhawk reported that he was having trouble engaging the pitch channel of the FAS.

The two aircraft took off at 1545 hrs and commenced their display at 1549 hrs. Towards the end of the display the Blackhawk flew, as programmed, on a heading of 70° approximately along the display line. It then carried out a 360° roll to the right which was initiated at the more easterly point and at an estimated height of 300 to 400 feet which was lower than in the practice on the Thursday.

Following completion of this roll there was an acceleration period of about 3½ seconds and the Blackhawk then pitched nose up and began to roll to the right while still pitching. When it had rolled through about 180° and the nose was about 15° below the horizon the roll rate decreased markedly and the Blackhawk then carried out what appeared to be an attempted recovery mainly in the looping plane, onto a north-westerly heading. It struck the ground tail wheel first at a high rate of descent whilst longitudinally level and banked slightly to the left. The impact point was 140 feet north of the display line. Fire broke out within one second of impact and the helicopter slid about 350 feet leaving a fire trail behind it. The aerodrome fire service were rapidly on the scene. They extinguished the fire and extricated the crew. The co-pilot was found to be dead whilst the commander died nine days later from the results of his injuries.



## 1.2 Injuries to persons

<i>Injuries</i>	<i>Crew</i>	<i>Passengers</i>	<i>Others</i>
Fatal	2	—	—
Non-fatal	—	—	—
None	—	—	—

## 1.3 Damage to aircraft

The aircraft was destroyed by impact damage and fire.

## 1.4 Other damage

There was no other damage or injury to people as the helicopter crashed on a clear part of the airfield.

## 1.5 Crew information

1.5.1 Both pilots were Sikorsky Aircraft test pilots.

1.5.2 Commander

Age 40 years.

Licence

USA Commercial Pilot's Licence with instrument rating, valid for rotorcraft including the S-67 Blackhawk.

Total pilot hours

Helicopter 3,484 hours

Fixed Wing 961 hours.

Total hours on S-67

In command 197 hours

Co-pilot 872 hours.

Total hours in last 28 days

7 hours, all on the S-67.

1.5.3 Co-pilot

Age 34 years.

Licence

USA Commercial Pilot's Licence with instrument rating valid for rotorcraft including the S-67 Blackhawk.

Total pilot hours

Helicopter 3,516 hours.

Fixed Wing 292 hours.

Total hours on S-67

In command 29 hours

Co-pilot 926 hours.

Total hours in last 28 days

6 hours, all on the S-67.

## 1.6 Aircraft information

- 1.6.1 The S-67 Blackhawk helicopter N671SA was the sole prototype of a Sikorsky attack helicopter. It was a civil registered aircraft, manufactured in 1970 and given the manufacturer's serial number 67001. The aircraft held a valid United States Federal Aviation Administration special airworthiness certificate. In this certificate the helicopter was classified as 'Experimental' and the 'Purpose of Flights' was stated as 'Research and Development, Crew Training, Exhibition and Market Survey'. Attached to the airworthiness certificate was a certificate entitled 'Experimental Operating Limitations' which stated in part: 'This aircraft does not comply with the Airworthiness Standards of ICAO Annex 8 and Part II; therefore flights are not authorised over foreign countries. Special permission must be obtained from foreign countries to conduct flights over their territories'. This permission was obtained from the Civil Aviation Authority for the flying done in the United Kingdom.
- 1.6.2 The Sikorsky S-67 Blackhawk was twin engined with a single main rotor and stub wings, crewed by two men who sat in tandem with the commander in the rear seat. The aircraft was derived from the Sikorsky SH-3, similar to the S-61, and it used the same engines and dynamic components as the SH-3. The five bladed articulated main rotor had a diameter of 62 feet and differed from that of the SH-3 in having swept back blade tips. The main landing gear was retractable into sponsons at the wing roots and the tail wheel was fixed. Airbrakes were fitted to the upper and lower surfaces of the outer wings, being operated electro-hydraulically by a 3 position rocker switch loaded to the centre 'off' position, located on each collective pitch lever. An 'AIRBRAKE OUT' warning light was located on the central panel.
- 1.6.3 The dual flying controls were of standard SH-3 type. The helicopter was fitted with a Stability Augmentation System (SAS) but this was always selected out for display flying. A Feel Augmentation System (FAS) operated on the cyclic control through roll and pitch channels. Roll FAS was always switched out for display flying and this made the roll trim inoperative. Pitch FAS was an electro-hydraulic mechanism which measured the aircraft load factor in a manner sensitive to aircraft pitch rates and then acted on the longitudinal cyclic control to provide the pilot with a constant stick force per 'g' of about 7.5 lb. at airspeeds above 80 knots IAS. Below 80 knots IAS the control forces were reduced linearly with airspeed to zero at 40 knots IAS. The system was duplex, outputs from the two actuators being summed by a yoke system. A fault detection capability was included to ensure system shut down in the event of a malfunction which could cause undesirable control inputs. Shut down time was stated to be very rapid – in the order of 100 micro-seconds. If a shut down occurred a 'FAS FAIL' light on the pitch FAS switch panel illuminated.
- 1.6.4 Pitch FAS passive failure produced no noticeable aircraft response in level flight but would remove any stick force being held by the pilot in dynamic flight. Pitch FAS runways were limited by the action of the duplex system, being characterized by a rapid 1 inch stick movement and a corresponding aircraft pitch rate. Control fixed runways would cause a 6 lb pulse to be felt by the pilot in the cyclic stick. The cyclic fore and aft stick trimmer was a thumb wheel used to supply a trim reference signal to a computer which in turn caused the FAS actuator to move the stick to the position selected by the pilot. The stick stopped moving when the stick sensor signal cancelled the thumb wheel signal.
- 1.6.5 The collective pitch FAS system used a signal from the normal visual rotor load indicator system to shake the collective pitch lever and thus warn the pilot that rotor loads were becoming excessive.
- 1.6.6 Two flexible bag type fuel tanks, comprising two cells each, were located in the bottom of the centre fuselage section. The two optional auxilliary tanks were not fitted; these are metal, foam filled (STAFOM) tanks, unlike the fuselage tanks which were not foam filled.

1.6.7 Up to the time of the accident the aircraft had flown a total of 598.7 hours and records showed it had been maintained in accordance with an approved schedule. The evidence was that the Blackhawk was fully serviceable at the start of the flight although the pilot of the CH-53 stated that the Blackhawk commander had reported on the radio (not on an ATC frequency and thus not recorded on tape) that he was having difficulty getting the pitch FAS engaged. The evidence was that this was a known characteristic of the system which often showed itself on the first flight of the day and could invariably be corrected by the pilot when the hydraulic system had been operating for a few minutes.

1.6.8 At start-up the aircraft's gross weight was at Sikorsky's normal display figure of 14,420 lb (max. permissible 22,050 lb), and the centre of gravity within approved limits. The aircraft took-off with 1,200 lb of fuel distributed equally between the two main tanks. There was a mixture of fuel in the tanks, calculated as being 650 lb JP5 and 550 lb Avtur (54:46 by weight).

1.6.9 The Blackhawk was cleared only for rolls to the right, at weights up to 18,700 lb and entry speeds between 120 and 150 knots. Auxiliary fuel tanks if fitted had to be empty.

**1.7 Meteorological information**

1.7.1 An observation made at Farnborough immediately after the accident was as follows:

Surface wind:	240°/12 knots, but variable 190° to 290°.
Visibility:	20 km.
Recent weather:	Showers
	1 okta 800 feet
	7 oktas 10,000 feet.
Temperature:	+ 14°C.
QFE	992.4mbs/29.31 inches.
QNH	1000.8mbs/29.55 inches.

1.7.2 Examination of the ATC local frequency tape, which contained regular wind reports to pilots, and of the anemometer trace established that the crash observation wind was typical of that at the time of the accident.

1.7.3 A meteorological assessment of the low level winds over the airfield at the time of the accident was as follows:

100 feet	240/250°	14 knots` )	) With gust of ± 7 knots and an approximate period from gust peak to peak of 3 minutes.
200 feet	240/ 250°	16 knots )	
300 feet	250°	18 knots )	
400 feet	250°	19 knots )	
500 feet	250°	20 knots )	

1.7.4 At the time of the Blackhawk's only practice at Farnborough, on Thursday 29 August 1974, the surface wind was 120°/12 knots.

## 1.8 Aids to navigation

Not relevant

## 1.9 Communications

The CH-53 and the Blackhawk were in communication with each other and with Farnborough ATC throughout their flight on the aerodrome control frequency of 126.4 MHz. Study of the taped record of this frequency revealed nothing that indicated any sign of trouble, and established that the accident occurred at 1553 hrs.

## 1.10 Aerodrome and ground facilities

A display line was laid out with 'dayglo' markers 400 feet north of the centre line of runway 25/07 for the benefit of display pilots.

## 1.11 Flight recorder

No flight recorder or cockpit voice recorder were fitted or required.

## 1.12 Wreckage

1.12.1 Examination of film evidence, and of the accident site, revealed that the Blackhawk first struck the ground with its tail wheel and port wing tip while in a slight left bank, with the fuselage longitudinally level at a high rate of descent, on a track of 325° (M) and a heading substantially the same. The main rotor blade tips then struck the ground on the port side of the helicopter, the sliding fuselage caught fire almost immediately and travelled on fire a total distance of about 350 feet before coming to rest.

### 1.12.2 Engines

Examination of the two T-58 engines, and their associated fuel control systems and instruments revealing that both engines were turning on impact and that there had been no pre-crash failure or malfunction. The fuel control input shafts of both engines were in a position corresponding to a demand for full free turbine speed.

### 1.12.3 Flight controls

Part of the linkage of the flight control system was severely damaged by fire. However no evidence was found to suggest any pre-crash failure or malfunction in any part of the hydro-mechanical flight control system. Bulb filament examination showed that the SAS and the roll FAS were both off, that the pitch FAS was engaged, and that the pitch FAS fail light was out.

### 1.12.4 Centralised Warning Panel

A comprehensive range of items was covered by the centralising warning panel. Bulb filament examination established that none of the lights were illuminated on impact. This indicated in particular that there had been no hydraulic, electrical, fuel system, or gear box failure of a type which could be detected by the warning system, that the speed brakes were in on impact, and that the canopy and access door were both closed.

#### 1.12.5 *Cockpit instruments*

Examination of the cockpit instruments revealed nothing of significance. The commander's (rear seat) pressure altimeter was set at 29.32 inches and the co-pilot's at 29.31 inches, the Farnborough QFE being 29.31 inches.

#### 1.13 **Fire**

Study of cine film revealed white fuel vapour rising from the bottom centre fuselage region half a second after the aircraft's tail wheel first struck the ground. One second after initial impact (ie half a second after fuel vapour was first evident) a fire started high up on the starboard side of the fuselage. The cause of the fire was vapour ignited by the starboard engine exhaust. The fire spread through the fuel vapour almost instantaneously enveloping the fuselage aft of the cockpit. The wind kept the fire back to just behind the cockpit. The commander suffered skin burns.

The aerodrome fire service had been supplemented by outside appliances and personnel for the week of the display and the vehicles were deployed in three groups on the airfield. The helicopter crashed near two of these groups which responded immediately, suppressed and finally extinguished the fire and extricated the two occupants. A crane had to be used to lift the fuselage to free the head of the rear crewman (the commander). A doctor was on the spot giving assistance throughout.

Ten fire and support vehicles were employed. Of these, two rescue vehicles used 300 gallons of water together with 18 gallons of 'lightwater' foam material, and four larger appliances used 4,450 gallons of water together with 350 gallons of protein based foam compound.

Both the fire fighting and the rescue aspects of the operation were expeditiously and efficiently executed.

#### 1.14 **Medical and pathological information**

Autopsy examination revealed no evidence of disease in either pilot, and there was nothing in their medical records to suggest a possible cause of the accident.

#### 1.15 **Survival aspects**

The death of the commander was due to a combination of complications of the injuries he received in the accident rather than to the injuries as such. He was unfortunate to have had the particular combination of complications that eventually caused his death and so from this viewpoint the accident can be assessed as survivable by the rear seat occupant. The co-pilot (front seat) could not have survived the severe multiple internal injuries he received. However it seems likely that many of these were sustained when he 'submerged' through the lap strap of his four point safety harness. If a five point harness incorporating a crutch strap, had been fitted the co-pilot might have survived. The accident is thus assessed survivable despite its severity and the death of the two crew members.

#### 1.16 **Tests and research**

##### 1.16.1 *Kine theodolites*

Although three kine-theodolite cameras had been set up to provide continuous coverage of the flying for purposes of display control and investigation of any

incident or accident at the show the only film related to the accident obtained from this source was post-impact.

#### 1.16.2 *Film analysis*

Fortunately three 8 mm colour films and a number of still photographs were obtained from members of the public and these were analysed in the investigation. One of the 8 mm films showed the whole of the Blackhawk's last roll and the accident in an unbroken sequence. The film evidence was analysed to establish the helicopter's final manoeuvre in detail. The technique used was to align the silhouette of a Blackhawk model so that it was co-incident with the projected image from each frame of the cine films, and so to establish the helicopter's position and attitude throughout the accident manoeuvre. These attitudes relative to the line of sight of the cine cameras were then corrected to give attitudes relative to the ground, and from these angular rates were derived and an estimated flight path constructed. A pictorial view of the final manoeuvre is illustrated at Appendix 1, a plan of the helicopter's estimated track is at Appendix 2, a graph of the helicopter's roll, pitch and azimuth attitudes and rates during the manoeuvre is at Appendix 3, and a comparison of the aircraft's pitch attitude with that shown on flight test data supplied by Sikorsky Aircraft is at Appendix 4.

#### 1.16.3 *Rotor speed*

Twenty four measurements of main rotor blade movement were taken from six frames of cine film occurring between 1½ and 2 seconds before impact. From these measurements the main rotor speed was estimated to be 204 rpm, which is normal. The film also showed that up to the time of impact the rotor was generating high thrust.

#### 1.16.4 *Height and airspeed*

The Blackhawk's height and airspeed at the start of the second roll could not be obtained directly from the film analysis but sensible flight path results could only be obtained for entry heights between 300 and 375 feet above ground level (AGL) and an entry indicated airspeed of 107 to 142 knots.

#### 1.16.5 *The manoeuvre*

The derived aircraft behaviour data (Appendices 3 and 4) show the Blackhawk's attitude history and rates of rotation during the last 10 seconds of the flight. Comparison of these with Sikorsky instrumented flight data of the roll manoeuvre as well as with film of practices at Woodbridge, and with company test pilot description of it, showed that whilst the helicopter's roll rates and attitudes achieved were normal the pitch rates and attitudes were very different. Firstly, the pitch attitude at the start of the roll was +6°, instead of the usual +15 to +20° stated by pilot evidence and the +19° and +23° shown in the instrumental flight data. Secondly, there was a pitch rate of about +9° per second at the start of the roll, whereas pilot evidence supported by Sikorsky flight data, was that this should have been reduced to zero before rolling commenced. Thirdly, at Farnborough the Blackhawk diverged markedly in pitch as the roll progressed, whereas the helicopter did not do this in a normal roll. After roll entry its pitch rate increased to +10° a second and stabilised there for 2 seconds by which time the roll attitude had reached 100°. The pitch rate then increased rapidly, reaching +30° a second as the aircraft rolled through the inverted position, at which point the nose was about 15° below the horizon, whereas in a normal roll it would have been about 9° above. At this point the roll rate fell off rapidly and the pitch rate increased further as the Blackhawk stopped rolling and entered a manoeuvre in the looping plane. At the bottom of this half loop the helicopter struck the ground substantially level and apparently under control but with a high rate of descent.

## 1.17 Other information

### 1.17.1 *Blackhawk rolling manoeuvre*

The technique employed when rolling the Blackhawk, and also the CH-53, is to approach the roll entry point at 120 to 150 knots IAS. The height of entry varied between pilots. The commander of the Blackhawk normally used a height of about 500 feet but other Sikorsky pilots preferred a height of 800 to 1,000 feet as they consider that this gave a greater margin of safety. The manoeuvre was initiated by pitching the nose up to a selected attitude and then ensuring that the pitch rate was zero before rolling the aircraft. The commander normally used a figure of 15° nose up, so as to complete the roll in level flight but with the nose depressed in an acceleration attitude. The commander of the CH-53, also a very experienced Blackhawk pilot, stated that he used 20° when rolling the Blackhawk to ensure that he did not lose height during the manoeuvre, accepting that he would have to make an adjustment to the aircraft's attitude at the end of the roll in order to accelerate to continue the display. The evidence of the CH-53 commander and analysis of instrumented roll data from early Blackhawk flights indicated that in a properly executed roll a pitch attitude of 15° nose up on entry should result in a negligible change of height during a roll manoeuvre. A pitch attitude greater than this would result in a gain of height, and one of less than 15° in a loss of height. When the helicopter is established at the selected nose up attitude with pitch rate at zero full right lateral cyclic control is applied. Collective pitch and yaw pedals are kept at their pre-roll settings throughout the manoeuvre, but 1 to 1½ inches of aft cyclic is applied whilst the aircraft is between 60° and 90° of roll and maintained until recovery is initiated as the wings level position is approached. If 15° nose up attitude is not obtained, or the pitch rate is not reduced to zero before the roll is initiated a loss of height will ensure, the magnitude of the loss depending on the pitch attitude and pitch rate pertaining when rolling commences.

### 1.17.2 *Flying display control*

On 13 August 1973 the then Parliamentary Under Secretary of State for Aerospace and Shipping wrote to the Director of the SBAC expressing his concern to ensure that the safety arrangements at the 1974 Farnborough Show would be of the highest order. The letter pointed out that a common factor in several accidents at air shows was that pilots had been attempting to demonstrate particular features of their aircraft in configurations or under circumstances in which the normal safety margins may have been eroded, and that unless adequate margins were maintained any unexpected malfunction or failure could all too easily lead to an irrecoverable situation and disaster. The letter expressed confidence that the lessons to be learned from previous accidents would be taken fully into account by the SBAC in planning the show and in framing the supporting safety rules, and that the Society would impress upon all those taking part in the display that configurations and manoeuvres in which adequate safety margins cannot be maintained would not be accepted.

The Director of the SBAC replied on 14 August favourably, and said the Minister's letter would be placed before the SBAC Flight Operations Committee. A meeting of this Committee, whose members are test pilots from British aircraft manufacturing companies, was held on 5 September 1973. Amongst those also attending were the Director of Flying (Research and Development) Ministry of Defence and representatives of the Civil Aviation Safety Adviser, Department of Trade and Industry and of the Airworthiness and Flight Safety Divisions of the Civil Aviation Authority.

The committee considered the SBAC Exhibition Regulations for the 1974 show in detail and their attention was drawn to the correspondence between the Minister and the Director of the SBAC. These regulations contained a section devoted to Flying Limitations in which the minimum height for all manoeuvres, other than level fly pasts, was specified as 200 feet. The consensus of opinion at the meeting was that the

height limitations which had been in force for a number of years for SBAC flying displays were adequate, but concern was felt that aircraft should only be permitted to perform and demonstrate manoeuvres consistent with the design role of the aircraft and, among other amendments, a clause to this effect was introduced into the flying limitations.

Subsequently a preliminary draft of the Flying Regulations incorporating the results of this review was produced and circulated to the members of the Flight Operations Committee which made further amendments, and a final draft was produced and circulated to the Director of Flying (Research and Development) Ministry of Defence, the Airworthiness Division Civil Aviation Authority, the Civil Aviation Safety Adviser, Department of Trade and Industry and the Director of Flight Safety Civil Aviation Authority, on 21 November 1973. The regulations were later endorsed by the SBAC Council and were published early in 1974.

At the time the regulations were framed it was considered by those concerned that they should apply equally to fixed and rotary wing aircraft. During the summer of 1974 written descriptions of proposed flight displays were received from exhibitors and it was noted that rolling manoeuvres were being proposed for certain helicopters. This was discussed among the members of the Flight Operations Committee who concluded that rolling manoeuvres for helicopters should be permitted providing it could be established that the aircraft were suitably stressed and that such manoeuvres would be within their design role ie the capacity to take violent evasive action by ground attack military helicopters and the capability to perform aerobatic manoeuvres by civil helicopters designed and sold for this purpose.

The Royal Aircraft Establishment (RAE) airfield of Farnborough is under the control of the Ministry of Defence (Procurement Executive) (MOD (PE)). The flying display presented by the Society of British Aerospace Companies (SBAC) as part of their Exhibition at Farnborough, is controlled by a Flying Control Committee mainly consisting of senior civilian test pilots. However, the Chairman was the Officer Commanding Experimental Flying Department at the RAE and he was charged by MOD (PE) with responsibility to them for the regulation and control of the flying.

Applications to participate in the flying display, are required to include a short resume of the proposed demonstration which is scrutinised by the Flying Control Committee, who are primarily concerned with safety. All aircraft participating in the flying display were required to give a demonstration of their proposed programme to the Flying Control Committee prior to the Exhibition. The two Sikorsky aircraft made such a presentation to members of the committee who considered that the display as presented was safe and complied with the SBAC regulations.

Initially, it was the manufacturer's intention that the CH-53 alone should participate in the flying display. The Blackhawk was added later and the appropriate SBAC documents were completed. These stated that the Blackhawk rolling manoeuvres would be carried out at 300-400 feet. Subsequent to their initial application, which was signed and authorised by the company Chief of Flight Operations, Sikorsky decided to stage a combined demonstration using the Blackhawk and a CH-53 helicopter. The two pilots concerned then evolved an amended flight demonstration routine. On 28 August this new routine was amended in writing by the commander for the Flying Control Committee. In this document a height of 200 feet was referred to for the execution of rolling manoeuvres. This amended routine was outside the knowledge of the Sikorsky Chief of Flight Operations and had not been approved by him. This was appreciated by the SBAC organisation.

Examination of the applications made by Sikorsky for the CH-53 (a US Military aircraft) after the accident to the Blackhawk revealed that the pilot flying the aircraft during the display was not the pilot who had been authorised by the Director of Flying MOD (PE) as Sikorsky Aircraft had substituted another pilot without informing the SBAC.



## 2. Analysis and Conclusions

### 2.1 Analysis

- 2.1.1 The photographic and eye-witness evidence showed that the accident occurred because a high pitch rate built up during the last roll. This resulted in an excessively nose down attitude when the helicopter was in the inverted position and the investigation was focussed on the reason for this excessive pitch rate and divergence.
- 2.1.2 The wreckage analysis brought to light no evidence of any pre-impact failure or malfunction of any sort in the aircraft, its engines, or systems. Because of the damage to the aircraft such evidence was not by itself conclusive. However, film evidence showed that the aircraft was in a controlled pull-out just prior to striking the ground in that it was not rolling or yawing and the pilot managed to achieve a level longitudinal attitude before impact, and that rotor speed was normal with the rotor generating high thrust. From this it is concluded that there was no catastrophic failure of the flight control system and the rotor was being driven normally.
- 2.1.3 As far as a minor failure (which would not have had catastrophic results at a greater height) is concerned, the only one that could have caused the excessive pitch rate shown on the film would have been a failure in the pitch FAS system. This, in a runaway case, could produce an aft stick input of 1 inch movement or a 6 pound stick force before the automatic safety device disengaged the system. However bulb filament examination established that the pitch FAS fail light was out, and thus that there had been no cut out of the pitch FAS system. A failure of this system is therefore discounted as a cause of the accident.
- 2.1.4 It is conceivable that some other minor technical malfunction occurring during the roll might have distracted the pilot sufficiently to cause him, in error, to apply excessive aft cyclic control. Such malfunctions include a door or canopy coming unlatched, the undercarriage or airbrakes deploying, or a spurious collective pitch shaker warning. All of these would make themselves evident to the crew and could provide the necessary distraction. The only one of these that cannot be discounted by technical and film evidence is the operation of the collective pitch lever shaker, but this would be expected to lead an experienced Blackhawk test pilot to relax, and not increase, the back pressure he was holding on the cyclic stick.
- 2.1.5 The other possible cause of the unusual nature of the roll manoeuvre (ie the excessive pitch rate) is an error of technique by the commander. The evidence is that if a roll is to be performed without loss of height it is vital that the pitch attitude prior to rolling must be at least  $15^{\circ}$  nose up and that the pitch rate be substantially zero. The photographic evidence established that as rolling started the Blackhawk was at an attitude of  $6^{\circ}$  nose up and with a pitch rate of about  $+9^{\circ}$  a second. Such an entry could have led to the pitch divergence seen on film if the controls had been used as they normally were to achieve a roll from the correct entry conditions as invariable practice was to apply 1 to  $1\frac{1}{2}$  inches of aft cyclic somewhere between  $60^{\circ}$  and  $90^{\circ}$  of roll.
- 2.1.6 Once the commander found himself inverted in a  $15^{\circ}$  nose down attitude he had two alternatives, as an inverted climb with negative 'g' was out of the question in a helicopter with an articulated rotor. The first was to continue the roll using longitudinal cyclic control and collective pitch to minimise height loss. The other was to recover in the looping plane and this is what he seems to have attempted. At the height the helicopter was when inverted the first alternative may have had a slightly better chance of success. However the commander might have been guided in his decision by not wanting to fly towards the spectators' enclosure, by reluctance to apply negative 'g' and/or by his original intention to follow the roll with a port turn.

- 2.1.7 The evidence of the three senior members of the Sikorsky ground support party, all of whom had seen many Blackhawk demonstrations, was that the helicopter came out of the 360° roll at a lower height than normal and that the acceleration period between the two rolls was much shorter than normal. Both they and members of the Flying Control Committee were agreed that the first roll was completed markedly further east than during the demonstration on 29 August. Comparison of wind data at the time of the two flights showed that wind effect could account for only a small amount of the difference in positioning. The audience on the day of the accident were concentrated at the eastern end of the airfield and this may have influenced the commander to start the first roll further east than he had done in practice. It seems probable that, having finished the first roll, the commander rushed his entry into the second in order to contain his display within the same bounds as the demonstration on 29 August. This resulted in the incorrect pitch attitude and pitch rate on entry which led to the nose down attitude when inverted, from which point the accident was almost inevitable.
- 2.1.8 Following upon the Minister's letter to the SBAC regarding display safety the Flight Operations Committee, together with representatives of the appropriate branches of the Department of Trade and Industry, the Civil Aviation Authority and the Ministry of Defence gave careful consideration to the display regulations. They concluded that the existing limit of 200 feet for manoeuvres was adequate but decided that each aircraft should only be permitted to perform manoeuvres consistent with its design role. When Sikorsky's entry was later received it was agreed by the Committee that rolling manoeuvres were within the Blackhawk's design role of attack helicopter.
- 2.1.9 Additional to the 200 feet limit the capabilities of each pilot/aircraft combination were assessed, as in previous displays, firstly by means of the entry certificate submitted by the company and secondly by the demonstration before the Flying Control Committee; whenever possible additional evidence on aircraft capabilities was also taken into account. In this case Sikorsky had specified a minimum entry height of 300 to 400 feet for the roll, and the demonstration was judged to be safe. The evidence is that the helicopter entered its final roll at a height of 300 to 375 feet. Thus although the commander started the last manoeuvre at a height above the minimum display height specified both by SBAC and the company, the entry height was insufficient to allow this very experienced display pilot to recover from the consequences of an error of judgement at the beginning of the final roll.
- 2.1.10 The Flying Control Committee considered the Blackhawk's proposed programme against the background of the 200 feet SBAC limit, the 300 to 400 feet entry height laid down by the Sikorsky Director of Flight Operations for a level roll, and the knowledge that both the commander and the aircraft had carried out hundreds of rolls in the past. The Flying Control Committee observed the manoeuvre performed correctly during the pre-show demonstration when it was started at some 400 feet and the aircraft did not descend below the entry height. In the light of what they saw and taking into account the experience of the pilot, the Flying Control Committee were satisfied that the display as demonstrated was safe. In these circumstances the committee considered that an ample safety margin was available. However an accident did occur and the question must be asked whether the height allowed an adequate margin of safety in the event of a divergence from the normal flight path such as might be caused by pilot misjudgment or distraction, especially bearing in mind the control characteristics of articulated rotor helicopters. It is perhaps interesting to note that the CH-53 and Bolkow 105 were rolled at a height of about 700-800 feet.
- 2.1.11 In general the control and supervision of the flying display by the Flying Control Committee was good. The shortcomings concerning the identity of the authorised CH-53 pilot, and the irregular change in the Blackhawk's notified minimum height for rolling manoeuvres were mistakes made by Sikorsky Aircraft which were difficult for the SBAC organisation to detect, and in the event it failed to do so.

## 2.2 Conclusions

### (a) Findings

- (i) The aircraft's documents were in order.
- (ii) The aircraft had been properly maintained and it was correctly loaded.
- (iii) There was no evidence of any pre-crash failures or malfunctions of the aircraft, its engines or equipment.
- (iv) Both pilots were properly licenced and adequately experienced for the proposed demonstration flight.
- (v) Post mortem examination of both pilots revealed no pre-existing disease or other medical condition which could have contributed to the accident.
- (vi) The control and supervision of the display by the Flying Control Committee was good.
- (vii) The SBAC Flying Display Regulations stipulated that aircraft should not fly below a height of 200 feet when executing aerobatic manoeuvres.
- (viii) The aircraft's proposed display routine had been demonstrated to the satisfaction of the Flying Control Committee prior to the Exhibition.
- (ix) Sikorsky Aircraft had cleared the helicopter to carry out roll manoeuvres at an entry height between 300 and 400 feet.
- (x) The final roll to the right was initiated at a height of between 300 and 400 feet.
- (xi) The helicopter was under control and the engines were developing power when it struck the ground.
- (xii) The post impact fire was caused when fuel from a ruptured tank ignited after contact with engine exhaust efflux.
- (xiii) The Commander made an error of judgement when initiating a roll manoeuvre at a low height. As a result the helicopter reached an unusual attitude at a height which was too low to allow recovery, although the roll was entered at a height which was adequate to comply with the minimum heights specified by SBAC and Sikorsky if the manoeuvre had been executed in the normal manner.

### (b) Cause

The accident was caused by the failure of the commander to establish the correct entry conditions for a low level roll manoeuvre and under the circumstances the height at which the manoeuvre was started was inadequate to permit recovery.

### 3. Recommendations

It is recommended that the height limitations for aerobatic manoeuvres for aircraft engaged in flying displays be reviewed in the light of this accident by the SBAC and MOD for future Farnborough displays and by the CAA for civil flying displays in general. Special consideration should be given to the height a pilot may require to recover from an imperfect manoeuvre, taking into account the capabilities of the individual aircraft.

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Accidents Investigation Branch  
 Department of Trade

January 1976

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