AIRCRAFT ACCIDENT REPORT 7/83

Accidents Investigation Branch

Department of Transport

Report on the incident to Sikorsky S76A Spirit G-BNSH at Aberdeen Airport on 16 October 1981

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15 March 1984

The Rt Honourable Nicholas Ridley
Secretary of State for Transport

Sir

I have the honour to submit the report by Mr K P R Smart, an Inspector of Accidents, on the circumstances of the incident to Sikorsky S76A Spirit G–BNSH which occurred at Aberdeen Airport on 16 October 1981.

I have the honour to be
Sir
Your obedient servant

G C WILKINSON
Chief Inspector of Accidents

Contents

Accidents Investigation Branch

Aircraft Accident Report No. 7/83
(EW/C772)

Operator:	North Scottish Helicopters Ltd
Aircraft: Type:	Sikorsky S76A Spirit
Nationality:	British
Registration:	G–BNSH
Place of Incident:	Aberdeen Airport Latitude 57° 12'N Longitude 02° 12'W
Date and Time:	16 October 1981 at 1145 hrs

Synopsis

The incident was reported to the Accidents Investigation Branch by an operator's representative at 1330 hrs on 16 October 1981 and the investigation commenced the following day.

The incident occurred during a two engine ground run with the rotor engaged when the aircraft was positioned outside the North Scottish Helicopters maintenance hangar at Aberdeen Airport. A fire broke out forward of the engines and behind the main transmission gearbox in the vicinity of the rotor brake assembly. The pilot, alerted to the fire by rising engine temperature indications followed by smoke in the cabin, shut down and evacuated the aircraft. Two ground engineers, monitoring the engine ground run from positions forward of the helicopter, fought the fire with a portable extinguisher until the arrival of the Airport Fire Service. The fire was extinguished by the Airport Fire Service but not without difficulty and only after substantial damage had occurred.

The report concludes that the fire was initiated by a brake puck or pucks dragging on the rotor brake disc producing frictional overheating of the assembly leading to a fire.

1. Factual Information

1.1 History of the Incident

The helicopter was positioned outside North Scottish Helicopter's maintenance hangar at Aberdeen Airport for an engine ground run. The object of this ground run was to dry the compressors of both engines after a chemical wash and to circulate the main transmission oil prior to taking a sample for routine analysis. The run was scheduled to be of ten minutes duration with both engines running and the rotor engaged. A single pilot was the only occupant with two engineers positioned forward and to either side of the aircraft to monitor the rotor disc.

The pilot completed all internal pre-flight checks which included ensuring that the rotor brake was selected 'On'. During the 'press to test' of the central warning panel (CWP) the 'ROTOR BRAKE' caption illuminated along with the other captions. Engine No. 2 was started and, after stabilising at ground idle for one minute the No. 2 DC generator was switched on. After checking that all No. 2 engine indications were normal, and obtaining a signal from the ground engineers that externally all was clear for rotor engagement, the rotor brake selector switch was moved from 'ON' to 'REL' (Release) then into the 'OFF' position. The 'ROTOR BRAKE' caution light extinguished and rotor engagement and acceleration appeared normal as No. 2 engine throttle was advanced to obtain 65-70% rotor RPM (NR). Engine No. 1 was then started and following stabilisation, the No. 1 DC generator switched on. After a short pause both engine throttles were advanced to flight idle and 100% NR achieved. All engine and transmission indications were then noted to be normal and the CWP clear of indications so the pilot began to time the ten minute ground run.

The run continued uneventfully for approximately 7½ minutes with all cockpit indications remaining normal. The pilot at that time was looking out of the cockpit monitoring rotor disc attitude when he heard a sudden rise in engine noise. On looking back to the instrument panel the power turbine inlet temperature (T5) digital repeater indicator lights caught his attention, all the lights including the reds were illuminated. One digital indicator was noted to be showing 846°C, the other in excess of 800°C. An immediate check of the analogue T5 gauges revealed them to be matched at about 950°C with the temperatures rising rapidly. Immediately realising that these indications were grossly outside normal limits the pilot closed down both engines by retarding the throttles and fuel levers fully aft, then selected rotor brake 'On'. The brake appeared to function normally.

Smoke started to issue from the radio equipment mounting area in the cockpit and simultaneously flames and smoke were seen, by the ground engineers, coming from both engine intakes. The pilot pulled both emergency shut down handles and selected the fire extinguisher to 'MAIN'. After completing shutdown of the electrical systems the pilot left the aircraft with the cockpit filling with smoke. There was no fire warning. Flames and smoke continued to pour from the engine intakes and the cowling around the main rotor head despite the efforts of the ground crew to extinguish the fire with a portable carbon dioxide fire extinguisher.

The fire was seen from the Airport Fire Service watchroom at the fire station, which is situated 200 metres from the helicopter's position, and vehicles were rapidly deployed to the scene. Initially the Fire Service experienced difficulty in gaining access to the seat of the fire because the tools carried on the fire appliances were incompatible with the fasteners on the aircraft panels. At the request of the fire officers the ground engineers removed panels from the engine intake area which provided access to the fire.

During the fire fighting a fireman reported what he thought to be hydraulic fluid leaking from a pipe in the plenum chamber and supporting the fire. As a result, an engineer entered the aircraft and selected the rotor brake to 'Release'. A further report of hydraulic oil leaking by the same fireman proved to be an engine lubrication oil pipe failure releasing oil into the plenum chamber.

The fire was brought under control and finally extinguished some 14 minutes after the first indications of fire were observed.

1.2 Injuries to persons

None

1.3 Damage to Aircraft (Fig 1)

Substantial fire damage occurred in and around the engine intake plenum area. The aircraft has since been repaired.

1.4 Other Damage

Nil

1.5 Personnel Information

Commander:	Male, aged 29 years
Licences:	Airline Transport pilots licence Helicopters and Gyroplanes issued by the Civil Aviation Authority in January 1981 with type ratings including Sikorsky S76 pilot in command
Last medical examination:	12 January 1981
Flying experience total:	1774 hours
Experience on type:	398 hours

1.6 Aircraft Information

1.6.1 General

Manufacturer:	United Technologies, Sikorsky Aircraft
Year of manufacture:	1980

Constructors No.:	760112
Registered owner:	Management Aviation Ltd
Certificate of Airworthiness:	United Kingdom Transport (passenger) Category valid until 5 February 1982
Total airframe hours:	665.50
Total engine hours (both):	665.50
Hours since last inspection (100 hr zone 1):	67

1.6.2 *Rotor Brake System* (Fig 2)

A rotor brake system is fitted to the aircraft to keep the rotor from turning when the helicopter is parked, while starting engines and to assist in stopping the rotors upon engine shutdown.

Two brake assemblies are mounted on the main gearbox housing, operating diametrically opposed on the same rotating disc which is bolted to the tailrotor drive shaft output flange at the main gearbox. Braking action is achieved when the two pairs of opposing pistons are actuated hydraulically clamping the disc. Movement of the pistons is opposed by springs within the cylinders which serve to withdraw the pistons on brake release.

Hydraulic pressure to operate the rotor brake is supplied by an hydraulic power unit mounted on the rear left side of the main gearbox upper housing. This unit contains it's own electric pump, reservoir, accumulator and control valve. The reservoir when full contains approximately ¼ pint of hydraulic fluid to MIL-H-5606 (DTD 585) Specification. The brake is controlled by the 'Rotor Brake' switch on the master switch panel of the centre console, which has positions marked 'ON', 'OFF' and 'REL' (release).

The rotor brake is inoperative unless both engine levers are at idle or below and the gas generator RPM ($_N1$) of at least one engine is below 56%, ie one 'ENG OUT' light is on. When the rotor brake switch is selected 'ON' under these circumstances, and the rotor head is turning, the pump will build up pressure in the system to 200 ± 10 pounds/inch^2 (psi) for stopping the rotors. Five seconds after the rotor RPM reads zero or if the brake is switched to 'ON' with the rotors stopped, hydraulic pressure is automatically increased to 430 ± 20 psi to prevent the rotor turning during aircraft parking. The accumulator will maintain this pressure for a period of approximately eight hours in the presence of normal seal and valve leak rates. A pressure relief valve limits ultimate pressure to 620 psi to cater for thermal effects.

With the selector switch left at the 'ON' position, if the hydraulic pressure decays, the pump will automatically be switched on to restore system pressure. When the switch is moved from 'ON' to 'OFF' and left at the 'OFF' position the brake will remain pressurised but should the pressure drop due to system leaks it will not be restored. On the selection of the 'REL' position a solenoid valve is energised releasing system pressure and thus releasing the brake. This is a latching solenoid and therefore the valve remains open when the selector switch is released and the switch returns under spring action to the 'OFF' position.

It is therefore important to note that with the switch in the 'OFF' position the brake can be either 'ON' or 'OFF' according to the selection immediately preceding the 'OFF' switching. That is to say the 'OFF' refers to the electrical power supply to the hydraulic power unit not the condition of the brake.

A caution light on the CWP marked 'ROTOR BRAKE', illuminates whenever there is a brake system pressure of 15 psi or more.

When the brakes are released a spring within each brake cylinder withdraws the brake pucks from contact with the disc (Fig 3). The compressive force created in the springs during brake application is reacted by a mushroom shaped adjusting pin held in position within the cylinder by a collet and jam nut. The jam nut is torque loaded to a value that allows the adjusting pin to move through the collet to compensate for brake puck wear. For the self adjusting mechanism to function correctly the force which will cause the adjusting pin to move must be greater than the force required to compress the return spring.

The puck to disc clearance required with the brake off is achieved by setting up the internal gap, which represents the distance which the piston must travel before the adjusting pin is advanced. The resulting puck to disc clearance is equal to the internal gap less the amount of caliper deflection during brake application. Typically an internal gap of .075 inches is set to ensure a minimum puck to disc clearance of .040 inches.

Preloading of the return spring should ensure that the piston does not move before a pressure of 20-25 psi has been achieved, that is not until 15 psi has been significantly exceeded. Therefore the rotor brake caption on the CWP should always illuminate before any braking action is achieved.

Rotor Brake Maintenance Information

The following extracts from the aircraft's maintenance documentation refer to work carried out on the rotor brake in the relevant period prior to the fire.

19.5.81	Worksheet Record
224.50 Airframe hours	"Alert Service Bulletin 76-66-9" (CAA Airworthiness Directive 010-06-81) "complied with". (The object of this bulletin was to increase puck to disc clearance from .025" to 0.45" minimum.) "Rear left and right calipers found to have insufficient clearance. Procedures carried out in accordance with 66-55-02 para B(2) and (3) calipers reinstalled and checked. Right hand rear caliper recorded .045" left hand rear caliper recorded .038". Rotor Brake Bled and checked for leaks."

31.7.81	Worksheet Record
460.00 Airframe hours	"Rotor Brake caption won't clear after disengaging". "Rotor Brake power pack replaced".
26.9.81	Worksheet Record
603.30 Airframe hours	"Rotor Brake puck worn to limits (4 off)" "Worn pucks removed, new pucks fitted system bled and functionally tested."

A list of manufacturers Customer Service Notes and Bulletins which relate to the Rotor Brake and which were issued prior to the date of this incident are detailed in Appendix 1.

1.7 Meteorological Information

A full meteorological observation taken immediately after the fire gave:

Surface Wind:		280°/13 Kts
Visibility:		60 Km
Weather:		Nil
Cloud:		1/8 Cumulus 2,000 feet 1/8 Altocumulus 10,000 feet 3/8 Cirrus 20,000 feet
Airfield Atmospheric Pressure:		
(QFE):		1006.4 Millibars
Temperature:	Dry bulb	9.1°C
	Dew point	0.5°C

The anemograph trace for the relevant period revealed a maximum gust of 20 knots with the mean speed fluctuating between 11 knots and 15 knots.

1.8 Aids to Navigation

Not relevant.

1.9 Communications

The fire was observed at 11.42 hrs by the fire station watchroom attendant who, after sounding the alarm informed Air Traffic Control (ATC) of the incident and Fire Service response using the direct telephone line. ATC noted the call but no action was taken to alert other emergency services such as the Local Authority Fire Service.

The next call to ATC was from 'Fire One' on the fire service Communications frequency (UHF2) at 11.56 hrs indicating that the situation was under control and that the outside brigade would not now be required.

1.10 Aerodrome and ground facilities

The following fire vehicles were available at Aberdeen Airport on 16 October 1981:

Land Rover Rapid Intervention Vehicle (RIV) callsign 'Fire 1'
3 Nubian Major Water Tenders callsigns 'Fire 2, 3 and 4'

The RIV and 2 Nubian Majors were deployed to fight the fire in G–BNSH. One Nubian Major was held in reserve and was only deployed during the damping down operation.

1.11 Flight Recorder

There was no requirement for a flight recorder and none was fitted.

1.12 Aircraft Examination

1.12.1 Initial Examination

The helicopter was examined in the hangar of North Scottish Helicopters at Aberdeen Airport on the day after the incident.

It was apparent that a fierce fire had burned in the area of the intake plenum chamber, forward of the engine intake firewall and behind the main transmission gearbox (Fig 1). The temperature profile within the bay at the time of the fire, as revealed by the varying degrees of damage and sooting, indicated that the fire had been centred on the rotor brake.

The rotor brake assemblies, exhibited clear evidence of severe heating which had produced a partially molten condition on some sections. The two hydraulic pipe connection bosses on the rear cylinders had fractured, and a section of cylinder wall had broken away on the right rear cylinder. The puck associated with this cylinder remained in contact with the disc whereas the other three had retracted fully.

The hydraulic power pack had suffered significant scorching, the reservoir sight glass was no longer in position and the hydraulic fluid reservoir was empty.

A section of the tail rotor drive shaft had melted where the shaft passed through the intake plenum chamber. The flow of molten metal indicated that this had occurred after the shaft had stopped rotating.

A flexible pipe mounted on the rear wall of the plenum chamber and carrying No. 2 engine lubrication oil had been damaged by the fire causing it to leak oil onto the chamber floor. The contents of the reservoir, approximately 1 gallon, had leaked away.

Both engines exhibited damage consistent with flame ingestion.

The Kevlar fibre reinforced panel forming the front wall of the plenum chamber along with various ducts of the same material mounted in the area had been consumed in the fire, leaving only bunches of blackened fibres. The fire had also penetrated through the floor of the plenum chamber into the baggage bay.

The inside of all local cowlings were soot blackened and scorched. In addition the inside of the forward transmission fairing and flying control closet from the upper deck to the cockpit, were also soot blackened.

The brake assemblies were removed for dismantling and detailed examination.

1.12.2 *Detailed Examination of the Rotor Brake Assembly*

The rotor brake assembly was removed from the aircraft and subjected to detailed examination initially at the operator's engineering base and subsequently at the Accidents Investigation Branch Wreckage Analysis Facility at Farnborough. The position of the adjusting pin in the jam nut was accurately recorded this being an indication of brake puck wear. Detailed measurements of the thickness of each of the four pucks were recorded at four positions around their periphery. These measurements revealed a variation of wear both around the periphery of the pucks and from one puck to another. However, the mean wear levels equated to approximately 50% of the maximum wear allowable. The puck friction material in all cases appeared to have been softened in the fire but had subsequently re-hardened.

Vickers harness tests were conducted on the four cylinders and values between 62 Hv and 69 Hv were obtained. An unheated control cylinder produced a hardness value of 94 Hv and a further series of tests on sections from the control cylinder, after heating, indicated that exposure to 380°C (716°F) for 5 minutes was sufficient to reduce the hardness to that measured on the brake cylinders of G–BNSH.

Load/extension checks on the brake release springs showed them to be considerably softer than similar springs from an undamaged unit. In particular the rear cylinders exhibited the softest springs and the greatest degree of thermal damage to the microstructure.

The tapered collets removed from three of the brake cylinders exhibited a small step at the base of the tapered surface. Examination showed that the steps had been produced by the sharp edges on the jam nut where the internal taper and external thread run out meet.

Examination of the disc revealed that the disc expansion slots were blocked with a coloured material. Analysis showed the material to be an alloy of iron and copper with elemental copper distributed around the grain boundaries. The brake puck material is composed of a dispersion of iron and copper particles in a non-metallic matrix.

The disc dimensions were checked and found to be within tolerances, however, the disc was found to be dished, the rim having been effectively displaced rearwards.

On dismantling the calipers, it was observed that the cross port seals had been degraded by heat to a substance black and powdery in appearance. When the pistons were removed from the cylinders all the remaining rubber seals were found in the same condition.

The pistons of the two rear cylinders appeared to have been exposed to higher temperatures than the forward pair with the cadmium plating on the return spring retaining collar flaking off.

All components within the assembly were intact although clearly heat distressed.

1.12.3 *Laboratory Examination of Components*

Globular material observed in the cylinder jam nut/collet bore was identified as cadmium, melting point 321°C (609.8°F).

The four brake cylinders manufactured from cast AZ92A Magnesium Aluminium Zinc alloy all exhibited microstructural evidence of overheating. The condition of both rear cylinders being consistent with temperatures in the melting range 470-595°C, (878-1103°F). The broken bosses on the two rear cylinders both exhibited intergranular fractures consistent with temperatures in the melting range.

1.13 Medical Information

None relevant

1.14 Fire

When the fire was first noticed by the ground crew they attempted to put it out using a mobile Carbon Dioxide (CO_2) extinguisher, directing the extinguishant into the engine intakes. When the rotor had stopped they tried pointing the extinguisher lance down into the main transmission cowling beside the main rotor head. Their considerable efforts produced little, if any, effect.

On seeing the fire from the Airport Fire Service watchroom at 11.42 hrs the watchroom attendant raised the alarm and informed ATC of the incident. ATC noted the call but took no action. The Local Authority Fire Service and other emergency services were not notified. On arrival at the helicopter the Rapid Intervention Vehicle, 'Fire One', started to combat the fire with the application of Bromochlorodifluoromethane (BCF) extinguishant through the No. 1 engine intake. This had a marked effect on the fire from the left side but the No. 2 intake continued to issue large flames. On the arrival of 'Fire Two', a Nubian Major, BCF extinguishant was introduced into the No. 2 engine intake.

'Fire Three' then arrived on the scene, another Nubian Major, and one of its crew, equipped with breathing apparatus, entered the now smoke filled cabin. A 1.5 Kg BCF hand held extinguisher was discharged in the cabin although there was no sign of flames. As 'Fire One' exhausted its BCF extinguishant, 'Fire Three' took over on the left side of the aircraft.

The baggage hold was opened to gain access to the aircraft batteries and found to be full of orange/brown smoke. A 1.5 Kg BCF hand appliance was discharged into the bay and the batteries disconnected.

An attempt to open cowlings to gain better access to the seat of the fire was unsuccessful because the tools carried by the fire service were incompatible with the aircraft fasteners. Panels were finally opened by two ground engineers using their own tools and not without some personal risk, both suffering from the effects of smoke inhalation. As the cowlings were opened the fire flared up again and was finally extinguished using water.

At 11.56 hrs the Airport Fire Service contacted ATC and requested that they cancelled the Local Authority Fire Service attendance.

All access doors and cowlings were left open to ventilate the aircraft. 'Fire One' and 'Fire Four', a reserve Nubian Major, remained at the scene to cover the cooling down period and returned to the station at 12.20 hrs.

Total extinguishants used:

Water	100 gallons
CO_2	2 x 10 lbs
BCF	3 x 50 Kg; 2 x 1.5 Kg

1.15 Survival Aspects

Not relevant

1.16 Tests and Research

Discussions between the Accidents Investigation Branch and the aircraft and rotor brake manufacturers resulted in a series of tests to simulate the incident, as well as confirm some of the certification trial results in the light of aircraft in-service experience.

1.16.1 Jam Nut Tests

A series of tests were conducted by the helicopter manufacturer to measure the hydraulic pressure required to move the adjusting pin through the collet for varying jam nut torque loading with differing collet and jam nut states.

With the jam nuts torque loaded to 20 ft lb, six pairs of cylinders were pressurised and the minimum pressure needed to move the pin through the collet recorded. The first series was conducted with the units 'as received', some with steps on the collets produced by the leading edge of the jam nuts as previously described. The pressures varied between 83 psi and 180 psi with a mean of 122 psi. The tests were then repeated following polishing of the conical surfaces which resulted in variations between 60 psi and 172 psi with a mean of 116 psi. Two cylinder assemblies were then re-checked with the conical surfaces wetted with hydraulic fluid on assembly which produced break out pressures between 90 psi and 146 psi with a mean of 114 psi.

Further tests were carried out in an attempt to establish the relationship between the hydraulic pressure required to move the adjusting pin through the collet and jam nut torque. This was achieved by varying the torque loading between 0 ft lbs and 20 ft lbs whilst checking the adjustment pin breakout force, initially on 8 cylinder assemblies in the 'as received' condition. At zero torque loading the force varied from 5 lbsf (1 psi) to 50 lbf (10 psi) and increased to between 365 lbf (74 psi) to 1000 lbf (204 psi) at 20 ft lb torque.

On one cylinder which exhibited a step in the collet, the pressure to move the adjusting pin was recorded for varying torque loadings both in the 'as received' condition and after polishing of the conical surfaces. In the 'as received' condition the breakout pressure varied from 34 psi to 147 psi as the torque loading changed from 5 ft lb to 26 ft lb compared with 50 psi to 192 psi after polishing

On a further cylinder the breakaway force of the adjusting pin was monitored as several readjustments of pin position occurred. Over thirteen cycles the force dropped from 420 lbf (86 psi) to 365 lbf (74 psi).

1.16.2 Dynamometer Tests

A programme of testing was carried out on a dynamometer at the Goodyear Wheel and Brake Testing Laboratory at Akron, Ohio, to explore the consequences of unscheduled puck to disc engagement. All the test runs were limited to approximately two minutes duration because of rig considerations independent of brake performance.

The test programme was arrived at following a re-appraisal of the original certification trials. The following areas were identified as having been affected by change or to have been less than totally representative of the aircraft system during the earlier testing:

(i) The puck material had been changed.

(ii) The rig disc mounting structure had been rigid compared with the somewhat flexible aircraft structure.

(iii) The aircraft hydraulic system produces a park pressure of 400 ± 30 psi but experience had shown that during immediate post stop parking with the brake applied the pressure could increase to 600 psi due to thermal effects; this being the pressure relief valve setting. This increase in pressure results in increased caliper/disc deflections during the park mode of operation.

A number of two minute drag and stop sequence runs were carried out where the torque loading of one collet was zero and the hydraulic pressure in the brake for the drag phase was varied from the reservoir head up to 24 psi.

With no hydraulic pressure other than that supplied by the reservoir head there was no measureable increase in brake or disc temperature during the drag phase. However, it was shown that with pressure of 26-30 psi, a temperature of 900°F could be achieved in two minutes and it was concluded that 2000°F could occur within 8 to 12 minutes with a pressure of 15 psi or greater.

The hydraulic pressure was used to simulate adjustment pin slip or over advancement as well as the results of pressure build up due to unlatching of the solenoid valve. Following pin slip or over advancement the force with which the puck is pushed against the disc will be determined by the collet grip on the adjustment pin, initial brake clearances and the disc/caliper deflection during the preceding brake operation.

One stop test was conducted with 3° of taper ground on the disc contact lining surface to see if the piston would jam in the cylinder. No permanent binding occurred and the piston return was normal after the stop.

During a stop from 100% NR without any puck dragging preceding the stop a lining fire was observed but it was not self sustaining. No leaks of hydraulic fluid were observed during any of the runs, stops or subsequent park brake applications.

1.16.3 *Proposed Modification Test*

The manufacturers proposed to modify the S76 rotor brake to incorporate torqueless grips as used on a number of other installations (Fig 4). The torqueless grip brake employs a pair of spring collars which grip the adjusting pin in place of the jam nut and collet combination. The collars are placed around the pin outside the rear of the cylinder and therefore only control advancement of the pin.

A further series of tests were conducted to simulate a worst case puck drag situation on a typical brake to the current aircraft standard and comparison of the results made with those from a similar run on the proposed modified brake employing torqueless grips.

The worst case simulation was achieved by denying hydraulic pressure to one cylinder whilst applying 600 psi to the other three. This resulted in the un-opposed piston producing a combination of disc and caliper deflection which resulted in a loss of running clearance for that piston lining on pressure release.

With no hydraulic pressure applied to the brake the disc was then accelerated to 100% NR equivalent in half a minute and held there for two minutes whilst the disc temperature was monitored.

On three runs with the original collet and jam nut assemblies temperatures of between 1400-1500°F were achieved whereas with the torqueless grips the temperature remained below 150°F.

1.16.4 *Flammability Test of Kevlar Fibre Reinforced Composites*

The material manufacturers supplied test data showing compliance with the relevant sections of the Federal Airworthiness Requirements Part 24, paragraphs 25.853. However, in tests conducted by the Materials Department of the Royal Aircraft Establishment at Farnborough it was found relatively easy to ignite the resin and produce a self sustaining fire which produced clouds of dense smoke. As well as causing nausea the smoke was found to contain a quantity of toxic agents.

1.16.5 *Ignition Temperatures for Rotor Brake Hydraulic Fluid*

The rotor brake hydraulic system fluid conformed to MIL-H-5606 (DTD 585) and the manufacturers supplied the following data:

Spontaneous Ignition Temperature at atmospheric pressure – 635°F
Flash point (open cup) – 200°F

1.17 Additional Information

A previous occurrence of a Sikorsky S76 rotor brake fire had been investigated by the Accidents Investigation Branch and three others were known to the aircraft manufacturers. The details of all four are set out below.

1.17.1 December 1980, Aircraft No. 760021, Aircraft Total Time 969 hours, Puck Total Time of 125 hours.

Circumstances:

A leak was discovered in one of the brake calipers and it was decided to disable the brake. In fact the circuit breaker in the brake warning circuit was pulled and not the one in the hydraulic power unit supply.

A fire was detected during taxiing.

Examination:

A caliper housing was found to be cracked as well as both disc and pucks exhibiting evidence of overheating.

Probable cause:

The circuit breaker pulled denied the pilot any warning of rotor brake operation and it was possible that the brake remained partially applied during run up and taxi.

1.17.2 March 1981, Aircraft No. 760058, Aircraft Total Time 387 hours, Puck Total Time 0 hours.

Circumstances:

Following a normal single engine start, brake release, run up and ground run the rotor brake was applied.

A fire was detected after brake application.

Examination:

A caliper joint leak was discovered but there was no evidence of puck drag or hydraulic power unit malfunction.

Probable cause:

Hydraulic leak during brake application.

1.17.3 April 1981, Aircraft No. 760161, Aircraft Total Time 0 hours, Puck Total Time 0 hours.

Circumstances:

Following a normal single engine start and brake release a fire was detected during the run up. The rotor brake was applied after fire detection.

Examination:

The caliper input hydraulic lines were found to be leaking but there was no evidence of hydraulic power unit malfunction.

Probable cause:

Disc overheated due to puck drag and subsequent leakage.

1.17.4 April 1981, Aircraft No. 760041, Aircraft Total Time 740 hours, Puck Total Time 47 hours.

Circumstances:

During a start with the battery disconnected the brake was slipping and so was selected to release. A fire was detected during the run up and a loud bang heard. The rotor brake was applied after fire detection.

Examination:

A caliper was found cracked with both pucks and discs showing evidence of overheating.

Probable cause:

As the battery was disconnected the brake was unable to release which led to overheating and subsequent leakage.

2. Analysis

2.1 General

Examination of the wreckage indicated that a fire had burnt within the intake plenum chamber and was centred on the rotor brake assembly. The brake components had all been exposed to a prolonged heat soak during the fire which precluded the indentification of any overheat existing within the brake assemblies prior to ignition. The fact that the rear cylinders had been subject to higher temperatures than the front pair at some time during the fire is probably due to the combined effects of screening of the front cylinders by the disc and the gearbox acting as a large heat sink. Although the rear right side puck remained against the disc after the incident it must be remembered that the brake was applied during aircraft shutdown after the fire had started and the cylinder was significantly damaged.

All four disc pads showed varying levels of wear both around their periphery and one to another. The mean wear however equated to approximately 50% of the maximum allowable despite the fact that the pucks were renewed 62 flying hours prior to the incident. Normal puck life, based on the replacements made by the operator due to puck wear beyond limits, was of the order of 600 flying hours. However, the amount of puck debris blocking the expansion slots of the disc was indicative of some rapid removal of friction material during the brake's application when the puck material was softened after the fire had started. This, along with the overload failure of the cylinders, probably caused by hydraulic pressure when the material was significantly weakened by heating, supports the witness evidence that the brake was effective during the aircraft shutdown.

The steps observed on the tapered surface towards the base of the collets was seen to have been produced by the sharp edge of the jam nut where the internal taper and external thread run out meet. The effect of the step would be to absorb jam nut torque loading in trying to crush the base of the collet rather than closing the collet around the adjusting pin. This would result in a lower than desirable force to achieve advancement of the pin through the collet. Tests carried out on collets in the 'as received' stepped condition and following polishing of the conical surfaces confirmed this point. The amount by which the collet grip was reduced was clearly dependent on the dimensions of individual jam nuts, collets and their associated steps.

The normal brake operating temperatures as designed, were known to exceed the ignition temperature of the hydraulic fluid used in the brake system. The dynamometer tests showed that a dragging puck which was being pushed against the disc either hydraulically or mechanically by a force equivalent to 15 psi hydraulic pressure could produce disc temperatures capable of spontaneously igniting the hydraulic fluid. In fact in some cases the pucks themselves produced a limited fire which could provide an ignition source for the fluid at considerably lower temperatures. This, however, only occurred during brake application and as in the case of G–BNSH the fire had ignited prior to braking it would appear that spontaneous ignition of hydraulic fluid on the braking surfaces probably occurred.

The presence of hydraulic fluid on the brake pucks and disc could be the result of either a small pre-existing leak which did not affect brake operation or the result of brake overheating causing degradation of the fluid seal material. In the subject accident the fire destroyed the brake unit seals along with some hydraulic connections and hence the source of the fluid leak could not be determined.

During the dynamometer tests no leaks occurred but on a number of previous aircraft incidents the manufacturers investigation concluded that the dragging puck or pucks led to hydraulic leaks.

The evidence obtained from the examination of the aircraft and the dynamometer tests leads to the conclusion that one or more dragging brake pucks produced a fire at the rotor brake. Though the exact mechanism for producing the drag could not be positively established, four possible causes of brake puck dragging are considered below.

2.2 Possible Causes of Brake Puck Dragging

2.2.1 Brake Pressure Induced by Thermal Effects

This mechanism could occur with the rotor brake selector in the 'OFF' position if the power pack solenoid valve was unlatched. Should the sealed brake system be subjected to heat soak in this condition then a positive brake pressure would be induced.

During the pre-start checks the pilot confirmed operation of the rotorbrake warning on the CWP. During the ground run the warning did not illuminate indicating that pressure had not reached 15 psi. As significantly more than 15 psi is required to move a piston against its return spring, hydraulic pressure alone cannot have produced the drag.

If, however, a puck was already against the disc any pressure would add to the puck to disc loading. This mechanism would require a pre-existing malfunction that would cause a puck to drag plus an unscheduled closing of the power pack solenoid valve.

Customer Service Bulletin 76-66-10/10A introduced an automatic release selection on the brake if the hydraulic pressure should increase to 15 psi with the selector switch at 'OFF' following a release selection. This bulletin had not been complied with although the materials were in stock. However, the mandatory requirements permitted installation 'not later than the next 100 hour inspection after receipt of parts'. The absence of this modification meant that if the pressure rose to 15 psi or more the pilot would need to respond to the 'rotor brake' caption on the CWP and make a release selection. The fact that the CWP 'Rotor Brake' caption had not illuminated even though the brake had reached very high temperature suggests that the solenoid valve was correctly latched and that there was no pressure in the system. The evidence therefore tends to discount this mechanism as being responsible for the puck drag and resulting fire.

2.2.2 *Jamming of the Piston within the Cylinder*

The particular piston cylinder arrangement on the Sikorsky S76A has been used extensively on other aircraft and although pistons are known to tilt during braking this has never resulted in a jammed piston. However, if a piston were to jam within its cylinder the opposing piston would produce caliper and disc deflections that would cause the self adjusting mechanism to over-advance. This would result in the loss of brake clearances and a dragging puck.

When an attempt was made during the investigation to jam a piston within its cylinder by grinding a taper on the puck surface it failed to affect free piston movement.

As the detailed examination of the pistons and cylinder bores revealed no evidence of piston jamming it is considered very unlikely that this mechanism led to the puck drag in this case.

2.2.3 *Improper Setting up of the Brake*

Since the rotor brake power pack had been replaced on 31 July 1981 at 460 airframe hours and new pucks had been fitted on 26 September 1981 at 603.30 airframe hours the brake had functioned without any reported problem.

The brake had been modified to incorporate CSB 76-66-9 which was intended to increase the puck to disc clearance to a minimum of 0.045 inches. However, the relevant worksheet indicates that after incorporation one puck to disc gap was 0.038 inches. CSB 76-66-9A requires three brake applications following this modification after which the clearance must be 0.045 inches minimum. This latter bulletin had not been complied with. However, the fact that one pad had a clearance of some 0.007 inches below the minimum should not of itself have produced a problem as the brake originally operated with a minimum clearance of 0.025 inches. It is considered therefore that the brake in this instant was not improperly set up to such a degree as to produce a dragging puck.

2.2.4 *Adjustment Pin Slip or Over-Advancement*

A number of factors could contribute to pin slip. Testing showed that with correctly torque loaded jam nuts a large range of grip forces could be achieved although in all cases the force was in excess of that required to collapse the return spring. Steps produced by the sharp edge on some jam nuts were present on a number of collets and were seen to reduce the grip force for a particular jam nut torque loading. The grip force was further seen to diminish with successive advances of the adjusting pin during testing which simulated puck wear. If these reductions of grip resulted in pin advance at a loading only marginally in excess of the spring force, then the rapid application of hydraulic pressure, as supplied by the power unit, could result in dynamic creep of the pin.

Over-advancement may occur if a piston having a pin with a low grip force is opposed by one having a pin with a high grip force. The piston with the low grip will adjust to compensate for the wear of both pucks, and disc/caliper deflections, thus eroding its clearance to the disc in the brake 'OFF' position. This effect could be increased if the opposing piston became tight within its cylinder due to corrosion or brake debris build up. The limiting case of a jammed piston was the worst case tested, simulated by blocking off the hydraulics to that cylinder.

If pin slip or over-advancement does occur it is possible to reach the situation on brake release where the relaxing caliper and disc deflections push the puck against the disc with a force equal to that required to drive the adjusting pin back through the collet. Since the forward cylinders are mounted on the gearbox, caliper deflection manifests itself as a rearwards and outboard movement of the rear cylinders, therefore it is the rear pucks which are most likely to drag from this mechanism.

Of the four possible causes of brake puck drag this mechanism is considered the most likely to have been responsible for the puck drag and resulting fire.

As a result of the investigation into this incident the manufacturer has instituted a modification which replaces the jam nut and collet with torqueless grips (Fig 4). Incorporation of this modification precludes the above mechanism from causing puck drag after brake release.

2.3 **Fire Development and Fire Service Action**

The notification of the fire reached ATC from the Airport Fire Service, an unusual route, and ATC did not notify the Local Authority Fire Service to prepare to provide back up in accordance with local instructions. The Airport Fire Service clearly assumed this had been done when they instructed ATC to cancel the request when the fire was under control. The fire absorbed a large percentage of the Airport Fire Service capability and clearly had the fire been more difficult to control the arrival of the local service would have been necessary.

The fire service were greatly hampered by a lack of direct access to the seat of the fire, there being no fire fighting access point in the relevant panels. They were unable to open the panels as they were not equipped with the correct tools and as a result the operator's engineers were requested to undo them. This resulted in men without protective clothing approaching the still burning aircraft and suffering from the inhalation of fumes.

It is believed that the Fire Service approach to extinguishing this fire was influenced by the knowledge that there were no occupants on board and that the helicopter would be repairable. If life had been at risk, the lack of tools to undo the panels would probably not have severely hampered access as all thoughts of minimising damage to the helicopter would have been abandoned.

The evidence of the Airport Fire Service indicates that an intense fire burnt for a considerable period. The only fluids consumed during the fire were approximately ¼ pint of hydraulic fluid, and some percentage of the gallon of No. 2 engine lubrication oil. The amount of lubrication oil burnt is unknown as the fire damaged pipes continued to leak oil after the fire until the sump was empty. With such limited amounts of flammable liquids available it is clear that the Kevlar fibre reinforced panels in the plenum chamber area must have helped sustain the fire.

The fumes from the fire found their way into the cabin via the transmission forward fairing and flying controls closet after the front wall of the plenum chamber had been breached. As the aircraft was parked into wind this probably produced a slight pressurisation of the plenum chamber driving the smoke into the cabin. However, the cabin heater fan draws air from the plenum chamber and delivers it to the cabin. If this fan had been switched on the toxic fumes and smoke from the fire would have been rapidly distributed throughout the helicopter.

Though the Kevlar composites comply with the relevant sections of the Federal Airworthiness Requirements, the relative ease with which the resin can be ignited, and the resulting dense smoke and toxic emissions, together make its use in areas where high temperatures are generated questionable.

2.4 The Hazards of Rotor Brake Fires

Quite clearly examination of all the circumstances of this fire shows that it was purely fortuitous that it occurred during a ground run and not at some stage during flight when, due to a combination of the fire and the toxic emissions an aircraft, passengers and crew could have been lost.

Under normal operating circumstances the rotor brake and disc attain high temperatures. When a stop from 100% NR is required testing has shown the friction material of the pucks capable of producing flame. It would seem appropriate therefore that the helicopter and brake manufacturers consider methods of reducing rotor brake temperatures together with the provision of a fire detection system and fire fighting access points for the rotor brake.

3. Conclusions

(a) *Findings*

(i) The aircraft had been maintained in accordance with an approved maintenance schedule and the documentation was in order.

(ii) All relevant mandatory modifications had been incorporated or awaited action within the permissible time limit for compliance.

(iii) The operation of the aircraft throughout the ground run conformed with the approved standard procedures of the operator.

(iv) The pilot who received no indication of the fire other than indirectly via rising engine temperatures acted promptly and correctly in shutting down the engines and switching off the aircraft electrical systems before leaving the smoke filled cabin.

(v) The Airport Fire Service responded promptly to the alarm raised by the watchroom attendant but fighting the fire was hampered by a lack of access to the seat of the fire.

(vi) The airport Air Traffic Control did not inform the Local Authority Emergency Services as they were required to do in accordance with the Airport Emergency Orders.

(vii) The fire was sustained by the Kevlar composite material used extensively in the plenum chamber area. Tests showed that the material was relatively easy to ignite and capable of producing a self sustaining fire which generated dense and toxic smoke.

(viii) The fire initiated at the rotor brake assembly and was caused by one or more brake pucks dragging on the disc probably as a result of over-advancement or slip of the adjusting pin.

(ix) Dynamometer tests and the review of previous incidents confirmed the potential for a dragging puck to produce a rotor brake fire.

(x) Incorporation of the torqueless grip modification precludes over-advancement or slip of the adjusting pin resulting in a puck being forced against the disc after brake release.

(b) *Cause*

The fire was caused by one or more brake pucks dragging on the brake disc after brake release causing high temperatures to be achieved leading to the ignition of the hydraulic brake fluid.

(c) *Contributory Factors*

(i) Unsatisfactory design features in the brake self adjusting mechanism insofar as heavy brake puck/disc contact was possible with the rotor brake released.

(ii) The inflammable nature of material used in close proximity to the rotor brake.

4. Safety Recommendations

It is recommended that:

4.1 Installation of the torqueless grips modification should be made mandatory.

4.2 Consideration be given to the potential for Kevlar fibre reinforced panels to support a fire and a re-assessment be made of their use in areas of high temperature where ignition sources are available.

4.3 Consideration be given to methods of reducing rotor brake operating temperatures.

4.4 Consideration be given to the possibility of providing both fire detection and fire fighting access points for the area of the rotor brake which has been shown under certain circumstances to be a potential fire source.

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