Sikorsky S76C Spirit, G-JCBJ

AAIB Bulletin No: 5/2004	**Ref: EW/C2003/10/02**	**Category: 2.2**
Aircraft Type and Registration:	Sikorsky S76C Spirit, G-JCBJ	
No & Type of Engines:	2 Turbomeca Arriel 2S1 turboshaft engines	
Year of Manufacture:	1999	
Date & Time (UTC):	11 October 2003 at 1200 hrs	
Location:	Cranfield Airfield, Bedfordshire	
Type of Flight:	Training	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - None	Passengers - N/A
Nature of Damage:	Structural damage to the tail cone	
Commander's Licence:	Airline Transport Pilot's Licence	
Commander's Age:	53 years	
Commander's Flying Experience:	11,800 hours (of which 1,920 were on type)	
	Last 90 days - 101 hours	
	Last 28 days - 28 hours	
Information Source:	AAIB Field Investigation	

Synopsis

The helicopter landed heavily from a practice rejected takeoff, following a simulated engine failure, during a short field or semi-oblique take-off profile. The helicopter was not fitted with a Flight Data Recorder (FDR), but data retrieved from the Cockpit Voice Recorder (CVR) was compared with flight test data and this showed a shorter than normal time spent in descent. In addition, both pilots recalled a higher than normal rate of descent and the absence of translational lift. The investigation concluded that the most probable cause of the heavy landing was the high rate of descent, which was in turn due to the absence of translational lift, possibly as a result of the manoeuvre being flown in a slight tailwind.

History of the flight

The accident occurred on a check flight for the handling pilot during which he was to complete a Licence Proficiency Check (LPC), an Operator Proficiency Check (OPC) and Instrument Rating Renewal. The helicopter was not fitted, and was not required to be fitted, with an FDR, but it was equipped with a 30 minute, closed loop CVR; spectral analysis of the CVR recordings revealed a number of flight parameters. The following therefore has been compiled from witness evidence and data retrieved from the CVR recording.

The examiner and the handling pilot briefed for the flight at East Midlands Airport. Part of the check flight involved flying a rejected takeoff following a simulated engine failure during a short field take-off profile. During the pre-flight briefing, both pilots checked the maximum gross training weight for this manoeuvre from the Weight Altitude Temperature (WAT) chart provided in the Rotorcraft Flight Manual (RFM). They planned to fly from East Midlands Airport to Cranfield Airfield, where the majority of the test manoeuvres and procedures were to be conducted, and then return to East Midlands after refuelling. The examiner, who was also the commander, planned that the handling pilot should carry out the required instrument flying manoeuvres first before accomplishing various general handling and practice emergency procedures.

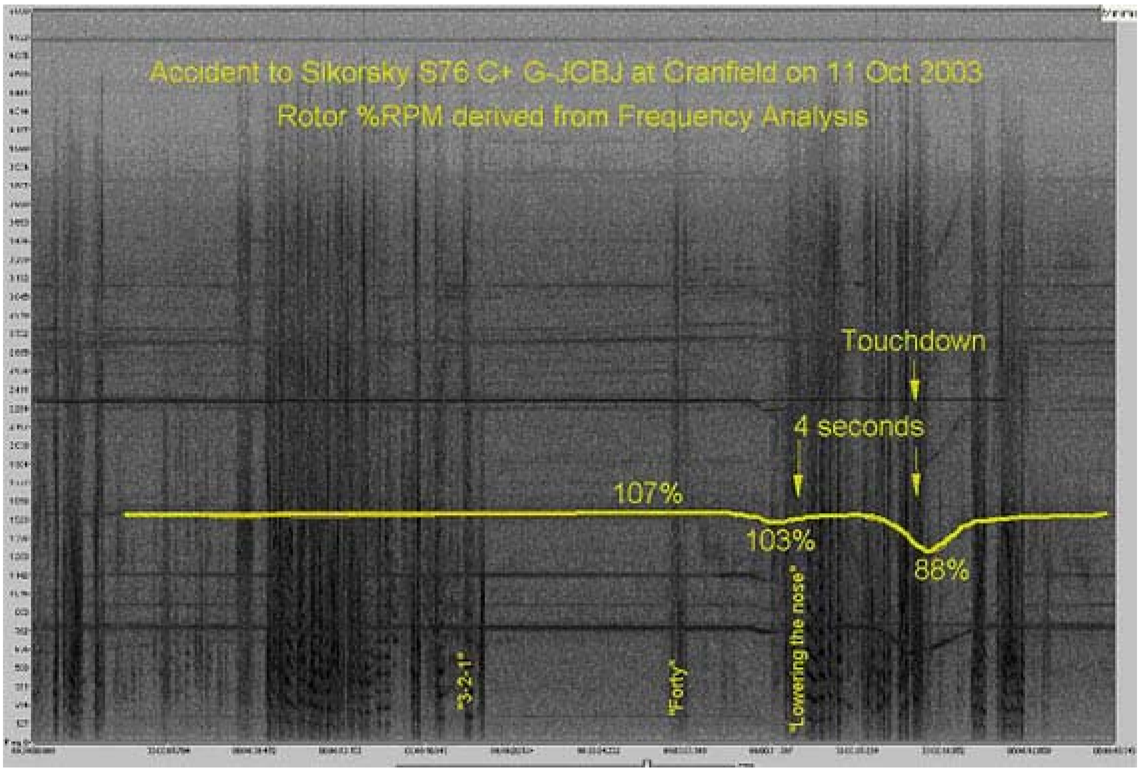
The instrument flying was completed without incident, and the crew then flew various one-engine inoperative (OEI) procedures during a series of visual circuits from the designated grass helicopter training area to the west of Runway 22 at Cranfield. The fuel used during these manoeuvres reduced the aircraft weight to below the calculated maximum for the short field rejected takeoff.

The short field take-off profile consisted of a full power climb with slight forward speed to a height of 40 feet agl and thereafter a vertical climb to a take-off decision point (TDP) from where a transition to forward flight would be made. The examiner planned to simulate the failure of an engine before the helicopter reached the TDP, and the handling pilot was expected to follow the rejected takeoff procedure and accomplish a landing straight ahead. The rejected take-off procedure required 650 feet of suitable landing area from the take-off point, and it was agreed with ATC that Runway 18 could be used. This provided about 1,600 feet of asphalt runway from the threshold of Runway 18 to the intersection with Runway 22 which was the active runway for fixed wing traffic.

The handling pilot briefly reviewed the short-field take-off procedure with the examiner, and TDP and airspeed bugs were set. The handling pilot then brought the aircraft to a 'wheels light' hover and counted down to the commencement of the manoeuvre. Both pilots recalled that the first half of the manoeuvre proceeded normally. The CVR recorded the examiner calling "FORTY" during the climb, and at about 130 feet above the ground the examiner simulated the failure of the right engine by use of the OEI Training Switch (see following OEI Training Switch paragraph for detailed explanation of the switch function). The handling pilot reacted to the simulated engine failure by lowering the nose attitude to 10° nose down and adjusting the collective downwards to contain rotor RPM (N_r) and prevent ballooning. At this stage the procedure requires the pilot to achieve translational lift which is indicated by a slight aerodynamic 'rumble' and/or flickering of the standby airspeed indicator; however, neither pilot can recall achieving this state, despite 10° nose down being maintained for most of the descent. Very soon after the apex of the manoeuvre the handling pilot realised that all was not well. Both pilots were aware of an abnormally high rate of descent and, as the helicopter passed an estimated 25 feet without the rate of descent apparently decreasing, the examiner removed his right hand from the OEI Training Switch to guard against any rearwards movement of the cyclic pitch control by the handling pilot. Both pilots applied full collective in an attempt to cushion the landing. The helicopter touched down hard on the left main landing gear, followed more gently by the right main landing gear and nose gear. An eyewitness positioned at the threshold of Runway 22 facing south-west, first saw the helicopter at the apex of its manoeuvre and thought that it was hovering at about 100 feet above the ground. He then saw it descend rapidly, and apparently almost vertically, to land hard on its main wheels.

Spectral analysis of the CVR recording (Figure 1) showed the N_r in the climb to be within the normal governed range at 107%. About nine seconds after the beginning of the manoeuvre the N_r reduced to 103% and then recovered to about 107% over the next four seconds before reducing again to 88% during the landing. The handling pilot announced that he was "LOWERING THE NOSE" just after the N_r reached 103% and two seconds later he stated "THIS DOES NOT LOOK PARTICULARY GOOD". Two seconds later the helicopter could be heard landing heavily. The total elapsed time from the start of the climb to the landing was about 16 seconds. The descent from the estimated apex of the manoeuvre to the ground took about five seconds.

Rotor %RPM derived from frequency analysis



After touchdown the brakes were applied and a request to ATC was made to taxi to the nearest dispersal where an inspection of the helicopter revealed a slight crease in the tail cone immediately aft of the point where the tail cone joins the main fuselage.

Meteorological conditions

An aftercast issued by the Met Office indicated that weather conditions over Cranfield at the time of the accident were generally good with a surface wind between 240°T and 280°T at five knots. Winds at 1,000 feet were 290°T at five to ten knots. Recordings of ATC messages passed to aircraft in the hour leading up to the accident revealed a variation in surface wind direction from 230°M to 320°M with the maximum speed of seven knots. However, the most northerly wind passed to the helicopter prior to the accident was 270°M / 5 kt and the last wind given to the helicopter before the accident was 250°M / 4 kt. All winds given by ATC were based on a two minute average. The helicopter's position during the accident manoeuvre would have placed it in the lee of the airfield hangars.

Examination of engines

The engines were removed from the airframe and subjected to an inspection at the engine manufacturer's overhaul facility in the USA. No damage was apparent.

Both engines were equipped with digital engine control units (DECU's) that contain non-volatile memory. These were interrogated by the engine manufacturer, who reported that there were no failure messages. The DECU's do not continuously record engine parameters.

The aircraft technical log indicated that the most recent power assurance check was conducted on 6 October, ie 5 days before the incident. This showed N1 margins for the No 1 and No 2 engines to be +3.7 and +9.1% respectively. Assuming no significant degradation occurred during the intervening period there was thus adequate power available up to the emergency ratings.

There was therefore no indication that an engine defect or malfunction contributed to the incident.

One-engine inoperative training switch

The Arriel engines have power ratings for both dual engine and single engine operation. Some of these ratings, notably single-engine 30-second and two minute power, are intended for use during actual emergencies. Use of these emergency power ratings reduces the time between engine overhauls, and they are thus not used routinely. To allow realistic OEI training to be carried out without affecting engine maintenance requirements, an OEI training facility is fitted.

The OEI training facility is selected through the OEI Training Switch, which provides reduced power levels for both dual engine and simulated single-engine operation but preserves realistic cockpit indications of gas producer speed (N1) and torque. The OEI Training Switch on this helicopter was located on the lower centre console, adjacent to the examiner's right hip. WAT graphs are provided for use with the OEI facility, and these provide a power to weight ratio for the ambient conditions that is equivalent to the aircraft being flown at maximum weight with full emergency engine power available. Thus in OEI mode the pilot experiences the same aircraft handling, climb rates, N_r droop and landing speeds as if the aircraft had suffered an engine failure at maximum take-off weight.

The OEI training facility has two modes. In Training Flight Mode the OEI Training Switch is placed in the Dual Engine Training position and de-rated engine power is available from both engines. In Training Idle Mode, the switch can be placed either in the No 1 or No 2 Engine Training Idle position and the selected engine is then governed at 91% N2. As a consequence, the engine selected to Training Idle is disengaged from the transmission by means of its freewheel and thus the engine provides no power. If N_r droops to 91% or below, the engine selected to Training Idle accelerates and so begins to provide power. Similarly, when Training Idle is deselected the engine will accelerate to join the other engine and provide dual engine training power. The remaining fully operative engine provides power exactly as if an actual engine failure of the other engine had occurred but to de-rated power levels. In the event of an actual engine failure, Training Idle Mode is deselected automatically. For safety reasons, the engine failure audio warning tones are suppressed in training mode but are activated for a real failure.

Short field take-off procedure

The following steps taken from the S76C+ RFM, Supplement 10, Part 1 describe the important points of the short-field take-off procedure:

5 Establish a wheels light near-hover with brakes released.

6 Check engine instruments.

7 Apply collective rapidly to achieve the take-off power limit (100% N1 or 100% torque) at 107% Nr and simultaneously lower the nose to set a 0° to -1° nose down pitch attitude.

8 At the takeoff profile nose up rotation point, 40 feet on the radar altimeter, the co-pilot announces NOSE-UP. Initiate a nose up rotation to approximately +15° and continue to monitor the effect on vertical trajectory by visual reference to the ground or obstacles. Adjust pitch attitude to obtain zero ground speed at approximately, but not before, 100 feet.

9 As the apparent trajectory becomes vertical, reduce nose up pitch attitude as required to prevent the initiation of rearward ground speed and continue vertical climb.

10 When the TDP tone is heard or the co-pilot announces ROTATE to coincide with the aircraft reaching the TDP radar height, input longitudinal cyclic to rotate to a 10° nose down attitude in approximately 2 seconds. The cyclic input defines the TDP; if an engine failure occurs prior to cyclic input, a reject is required, and during or after input, a continued takeoff is mandatory.

The RFM also provides a list of limitations that apply to the above manoeuvre, the most relevant of which are a 15 kt crosswind limit and the fact that *downwind operations are not permitted.*

Reject procedure from a short-field takeoff

The same RFM Supplement, outlined above, provides a procedure to be followed in the event of engine power loss during a short field takeoff. The procedure is divided into two sections determined by whether the power loss occurs before or after reaching 40 feet in the initial climb. The latter is relevant to this accident and reads as follows:

Engine power loss during the deceleration phase (After +15° nose attitude has been stabilised ....prior to the TDP)

1 Momentarily lower the nose to reach approximately -5° to -10° pitch attitude. Simultaneously reduce collective sharply to contain rotor rpm and minimize ballooning. Establish effective translational lift airspeed, then bring the nose back to the level attitude. To prevent excessive land back distance, avoid accelerating to airspeeds resulting in ground speeds above 20 to 25 KIAS.........

2 Adjust collective pitch downward as necessary to establish a steep angle of descent to touchdown at a point short of the available rejected takeoff area.

3 A rate of descent of 700 to 900 feet per minute is desirable and it might be necessary to reduce collective below 30-second power. Maintain level nose attitude to avoid appreciable loss of translational lift. If the rate of descent increases sharply, be prepared to contain the rate by lowering nose attitude to accelerate and increasing collective against the 30-second power limiter. Do not droop the rotor below 104 to 106% Nr until at or below approximately 15 feet.

4 As ground contact becomes imminent, reduce rate of descent for touchdown by adjusting the nose attitude to a maximum of 10° nose up. At or below about 15 feet, apply collective with sufficient rate and amplitude to effectively use the rotor inertia and cushion ground contact in a slow running landing.

Part 2 of the RFM Supplement, outlines provisions to be followed when carrying out the above procedures during training. The provisions require a specific initial training programme for pilots and a re-currency check every six months. The training provisions state:

Cautions and recommendations to be aware of during training include, but are not limited to, the rigid adherence to the limitations and procedural descriptions found in the supplement..........The instructor must remain poised during simulated single engine work to immediately re-select TRAINING FLIGHT (dual engine training) and then reposition to follow through on the flight controls at the earliest indication that a manoeuvre is not proceeding as desired.

The Supplement further advises that:

Rejected takeoffs should be approached in an incremental build down from 200 feet with the 100 foot altitude point being critical.

Finally in relation to re-currency, the Supplement states;

The Semi-Oblique Takeoff with subsequent engine failure requires considerable precision and is not altogether intuitive. All engines operating practice of this manoeuvre will aid in refreshing the pilot as to the feel and sight picture obtained when the manoeuvre is flown properly.

Training risk

The Semi-Oblique or Short Field Take-Off procedure was designed by the helicopter manufacturer and approved by the CAA for use by UK operators, in accordance with laid down policies. One of the latter requires that it should be flyable by a qualified pilot of average ability. Nevertheless, as the RFM Supplement describes, it is a demanding manoeuvre which requires some precision and practice in order to be flown well. The RFM recommends that an incremental approach to OEI training should be adopted. However, the relationship between the WAT training limit and the relatively high basic weight of the S76C+ means that OEI vertical and short field rejected take-off training is nearly always conducted at a weight that is equivalent to the actual aircraft being flown at the maximum certified weight for the prevailing ambient conditions. The performance margins are therefore invariably very close to the minimum required by the certification process.

The procedure is of a type that operators might opt to confine to simulator training. However, the relatively limited availability of S76C+ simulators and the high simulator fidelity required to make this sort of training realistic tends to mitigate against this option. Other experienced S76 operators advise that there are other means of reducing training risk, for example, by conducting the training without touching down (the LPC/OPC does not specifically require a landing to be conducted from the manoeuvre) and practising manoeuvre-abort procedures before beginning OEI training.

Tests and research

During the course of the investigation, the manufacturer and the CAA test pilot who had been involved in the UK certification of the manoeuvre were consulted. The manufacturer advised that no testing had been conducted in tail wind conditions and none was required by the certification process. However, it was anticipated that a tailwind would have a significant effect on performance. Furthermore, *"failure to achieve translational lift due to the tailwind performance loss and the associated increased sink rate (made it likely that) the power available was less than the power required to arrest the excessive descent rate"*. The manufacturer further advised that while the possibility of the helicopter experiencing vortex ring state could not be completely eliminated, the manufacturer's experience and other analysis indicated that it was relatively unlikely.

The CAA test pilot advised that the precise technique at the apex of the manoeuvre was important if higher than normal rates of descent were to be avoided. Whilst the first action listed in the reject procedure in the RFM requires the helicopter's nose attitude to be lowered it also states that the collective should be lowered simultaneously. The CAA test pilot advised that the handling at this point was critical. If the nose attitude was not lowered promptly before any reduction of the collective, it was difficult quickly to achieve forward speed and therefore translational lift. On the other hand if there was a significant delay in lowering the collective, a greater than desirable rotor droop could take place. Data derived from test flights conducted during the certification process showed that the test pilots were deliberately delaying lowering the collective by 0.62 to 1.74 seconds (the lower the TDP being used the shorten the delay). The minimum N_r seen at the apex of the manoeuvre was about 95.5%.

Further examination of the flight test data for the certification flights reveals that, although the RFM procedure implies that, at least initially, 30-second power should be selected, the operating engine was not producing full 30-second power during the whole descent. (The technique for setting 30-second power is to apply collective until the N_r droops to between 104% and 106%. During the test flights the N_r on several of the tests recovered back to 106% to 108% indicating that less than 30-second power was in use.) The emphasis, however, is on touching down within the available rejected take-off area and the procedure makes it clear that it might be necessary to reduce the collective below 30-second power to achieve the correct flight path. However, the procedure also states that if the rate of descent suddenly increases the collective should be increased to achieve 30-second power. It might be expected therefore that, on the accident flight, 30-second power, would have been set once a higher than normal rate of descent had been identified. However, the fact that the N_r, after an initial droop to 103%, recovered to 107% may indicate that 30-second power was not set for the descent.

The flight test data also showed that the time spent in the climb was almost identical to the time spent in the descent after commencement of the reject procedure. Assuming that the climb on the accident flight had been flown in accordance with the procedure, the fact that the descent lasted for only about two thirds of the time for the climb suggests that the rate of descent for the accident flight may have been significantly higher than on the test flights.

Previous accidents

This is the third accident in the UK involving damage to a helicopter caused during practice of rejected vertical or short field take-off profiles. Two have involved the S76C+ whilst one occurred to the S76B. All three accidents occurred during very light wind conditions.

Discussion

The helicopter suffered damage to the rear fuselage following a heavy landing from a practice rejected short-field take-off procedure. Both pilots were aware of a higher than normal rate of descent and despite the application of full collective during the landing they were unable to prevent the helicopter striking the ground hard on its left main landing gear.

The engines were examined and found to be serviceable, and regular power assurance checks showed that the engines were producing rated power. A problem with the engines is therefore considered unlikely. Advice from the manufacturer and a CAA test pilot indicated that there were several other possible causes of a higher than normal rate of descent.

Vortex ring state would explain a higher than normal rate of descent, but the manufacturer and other experts consider this unlikely. Furthermore the fact that the helicopter responded normally to the collective during the landing also makes it unlikely that vortex ring was the cause.

Without FDR evidence it is not possible to be certain of the cause of the high rate of descent, but spectral analysis of the CVR data and witness evidence provide some indication of possible causal factors. Both pilots are adamant that the apex of the manoeuvre was flown in accordance with the RFM procedure. However, the N_r drooped only to 103% which when compared to lower values of N_r at the same stage during certification test flights suggests that there was very little delay in lowering the collective at the beginning of the manoeuvre. The CAA test pilot advised that a rapid loss of height could occur if the collective was lowered too early in the procedure. The handling pilot's very rapid recognition that all was not well may also point to a problem at the apex of the manoeuvre.

The CVR spectral analysis shows that the N_r recovered to within the governed range (107%) during the descent, and this may indicate that 30-second power was not set on the sustaining engine. Although, flight test data indicates that full 30-second power was not always used during tests in headwind conditions, the RFM procedure requires 30-second power to be set if a high rate of descent condition develops. This would have been indicated by the N_r being in the range 104% to 106%. Thus it is possible that insufficient power was set on the sustaining engine during the descent, and this may partially account for the higher than normal rate of descent.

Both pilots are certain that the helicopter did not achieve translational lift, despite a 10° nose down attitude being maintained for most of the descent, and the witness on the ground thought that the descent was vertical. Both these factors point to the crew having difficulty establishing forward air speed. The winds recorded by ATC and passed to the helicopter indicated a wind about 70° to the right of the helicopter nose at around 5 kt. However, the wind may have veered as the helicopter came out of the lee of the airfield hangars during the climb, and the manoeuvre may therefore have been flown in a slight tailwind which may also help to account for the failure to achieve translational lift. The manufacturer has stated that lack of translational lift could have a significant effect on performance.

The OEI training system is designed such that the simulated failed engine idles at 91% and if the N_r droops below this figure the engine will start to provide power. In fact spectral analysis of the CVR showed that, although the N_r drooped below 91%, it did so only just before the helicopter touched the ground, and therefore even if the 'failed' engine had started to provide power it would probably have been too late to prevent the hard landing.

Similarly, the commander stated that he normally conducted the manoeuvre with his right hand on the OEI Training Switch so that he could re-select Dual Engine Training in accordance with RFM advice if the need arose. In the event, his reaction when he recognised the impending hard landing was to remove his hand from the switch to guard against any rearwards movement of the cyclic pitch control by the handling pilot. His left hand was already on the collective to assist the handling pilot with any application of that control. Again, it is possible that even if he had selected Dual Engine Training at that stage it might have been too late to prevent the hard landing.

Safety Recommendations

The short field and vertical operations outlined in the RFM are demanding manoeuvres to fly. In training they are made more so by the fact that the relatively high basic weight of the helicopter requires that they are flown at a power to weight ratio very close to the certified limit. Ideally training for the manoeuvre might be confined to a simulator, but there are practical difficulties associated with simulator availability and fidelity. The RFM highlights the training risks involved in flying the manoeuvres and suggests strategies for reducing those risks. However this is the third similar training accident in the UK in five years. It is therefore recommended that:

Safety Recommendation 2004-04

The Civil Aviation Authority require operators of the S76 to carry out an analysis of the risks associated with flying vertical and short field rejected takeoff manoeuvres with a view to mitigating the risks as much as possible.

This accident, and the other two similar accidents, took place in light wind conditions where there was no reported tailwind, and any tailwind that might have existed would have been light. It would therefore appear that even a slight tailwind can cause a significant reduction in helicopter performance. The risk of encountering an unexpected tailwind when operating in light and variable winds or winds close to the beam are increased, and it is important that pilots flying this manoeuvre in such conditions are aware of those risks. The CAA approved the manoeuvre for use by UK operators. It is therefore recommended that:

Safety Recommendation 2004-05

The Civil Aviation Authority require Sikorsky to rewrite the S76C+ Rotorcraft Flight Manual to emphasise the potential hazards when flying vertical and short field rejected takeoff in light winds or winds close to the beam.

Whilst it has not been possible to determine the exact cause of the high rate of descent, there remain doubts about how the manoeuvre was flown initially and the power setting of the sustaining engine. The RFM is not clear on the technique for flying the apex of the manoeuvre, and it is also vague on the required power setting technique. The CAA approved this manoeuvre for use by UK operators. It is therefore recommended that:

Safety Recommendation 2004-06

The Civil Aviation Authority require Sikorsky to rewrite the S76C+ Rotorcraft Flight Manual to make the required handling techniques for the rejected takeoff from the short field or semi-oblique take-off profile clearer.