Sikorsky S76C+, G-XXEA

AAIB Bulletin No: 9/2002	**Ref: EW/C2002/3/3**	**Category: 2.2**
Aircraft Type and Registration:	Sikorsky S76C+, G-XXEA	
No & Type of Engines:	2 Turbomeca Arriel 2S1 turboshaft engines	
Year of Manufacture:	1998	
Date & Time (UTC):	11 March 2002 at 1845 hrs	
Location:	Blackbushe Airport, Hampshire	
Type of Flight:	Private	
Persons on Board:	Crew - 2	Passengers - None
Injuries:	Crew - None	Passengers N/A
Nature of Damage:	Crease in underside of tailboom	
Commander's Licence:	Airline Transport Pilots Licence (Helicopters)	
Commander's Age:	50 years	
Commander's Flying Experience:	8,500 hours (of which 570 were on type)	
	Last 90 days 43 hours	
	Last 28 days 23 hours	
Information Source:	AAIB Field Investigation	

History of the flight

The flight was a training sortie for the handling pilot to accomplish recurrent training in night, one engine inoperative (OEI) procedures. Engine failure during short field takeoffs and landings was to be practised first and, when the aircraft weight had decreased sufficiently, the training was to progress to engine failure during vertical operations. The following has been compiled from the evidence of the crew and data extracted from the FDR.

A Met Office aftercast showed that the weather was generally fine with occasional outbreaks of light rain or drizzle. The surface wind was 240° at less than 5 kt, increasing to 240°/5 kt at 500 feet. The visibility was good under a cloudbase of 900 feet agl.

The short field training procedures were carried out using Runway 26 and progressed uneventfully. Before commencing the vertical procedures, the crew checked the surface wind with ATC and were informed that it was "generally calm with any drift coming from the north-west". The training captain therefore decided to conduct the vertical procedures training at the intersection of taxiway

'C' and Runway 26, which would allow the aircraft to face into the reported north-westerly wind. This location provided four blue taxiway lights as references by which to judge the vertical (in climb and descent) and a runway light on the northern edge of the runway as a heading reference.

Vertical takeoffs are normally conducted from sites where an immediate transition to forward flight cannot be made because of obstacles. The vertical takeoff procedure involves a vertical climb at full power to a Take-off Decision Point (TDP), after which a transition to forward flight is made. The height of the TDP is selected to ensure adequate clearance from obstacles, if the takeoff is continued and an engine failure occurs during the transition to forward flight. An engine failure before reaching TDP requires the takeoff to be rejected and a landing to be made back at the takeoff area.

The crew planned to practise rejected vertical takeoffs using, in sequence, TDPs of 70 feet, 100 feet and 40 feet, with the training captain simulating the failure of an engine just prior to the aircraft reaching the TDP height. Vertical landings were to be carried out using TDPs of 40 feet and 70 feet, while forward movement in the descent of up to 200 feet would be made from 100 feet. To ensure that handling procedures were correct before simulating the failure of an engine, the first two practices from 70 feet were to be carried out with both engines operating.

The all engines operating and the one engine inoperative practices, using a TDP of 70 feet, proceeded uneventfully. The training captain, who was seated in the left pilots' seat, briefed the handling pilot for practice from a TDP of 100 feet. The first practice from 100 feet was successful and the only points debriefed by the training captain were the need for a slightly earlier application of increased collective to cushion the landing and more forward movement in the descent.

The training captain briefed the handling pilot for a second practice using a TDP of 100 feet and the aircraft was held in a low hover with the wheels just touching the ground. After a countdown, the handling pilot raised the collective and achieved 100% torque on both engines. The helicopter entered a stable climb at 1,000 feet per minute and, at just over 100 feet radio altitude, the commander simulated the failure of No 2 engine. The handling pilot lowered the collective smartly to 23%, the main rotor speed (Nr) reduced to 105% and, in accordance with the standard operating procedure, the training captain began to announce the Nr ("one-oh-five").

The FDR showed that the aircraft achieved a maximum height of 119 feet, one and a half seconds after the simulated engine failure, and then began to descend. Over the next one and a half seconds, the Nr increased to 107% and the collective was raised slightly to 28% of travel. The No 1 engine torque values averaged 90% (30 second torque target 135%) during this period. As the aircraft descended through 100 feet, the training captain began his third announcement of Nr "one oh five" although, by this stage, the FDR indicated that the Nr had increased to a stable value of 108%.

The FDR showed that the rate of descent increased to a peak of 2000 feet per minute at 50 feet agl . The handling pilot remembered being aware of a higher rate of descent than during the previous practice from the same height. During the initial phase of descent, the handling pilot increased the collective from 28% to 30%, and finally to 34%. At about 45 feet above the ground, the training captain also became aware of the higher than normal descent rate and called "PULLING" as he assisted the handling pilot to cushion the landing by applying increased collective. The FDR showed that the collective was raised progressively to 91% and, two seconds before touchdown, No 1 engine torque increased rapidly to 150% (the allowable 5 second torque transient) and Nr began to decay.

The aircraft landed firmly and bounced forward before landing again and coming to a halt about 80 feet forward of the takeoff position. Nr had reduced to 91% at the initial touchdown and as it reduced further, No 2 engine began to provide additional power.

The training captain again debriefed the handling pilot on the need for a slightly earlier increase in collective and the crew discussed the severity of the touchdown. The training captain, who was a very experienced helicopter test pilot, considered the touchdown to have been no worse than "firm". The crew then completed the training detail with two practices using a TDP of 40 feet and one more from a TDP of 100 feet.

On completion of the sortie, the crew advised the ground engineers that they had experienced a firm touchdown. On inspection, the engineers discovered a crease in the airframe at the point where the tail boom is joined to the main fuselage.

Examination of the Aircraft

The helicopter was examined in its hangar at Blackbushe airport. The only visible damage comprised an obvious crease in the skin on the underside of the tailboom, just aft of Station 300 (the manufacturing joint line). Internally, a longeron had buckled where the crease was deepest.

Although no other damage was evident, both engines were changed as a precaution and a newly manufactured tailboom was fitted. Special checks of the drivetrain revealed no abnormalities.

Early access to the comprehensive Flight Data and Cockpit Voice Recorder information did not suggest that any form of mechanical, structural or electrical malfunctions were involved in the incident. Thus, an in depth examination or testing of the helicopter by AAIB was not warranted.

OEI training mode.

The Arriel engines have several power ratings, some of which are intended for limited use during actual emergencies. Use of these emergency power ratings may affect engine time between overhaul. 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 N1, torque and limiter usage. Weight, Altitude and Temperature (WAT) graphs are provided for use with the OEI facility. 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, Nr droop, descent rates and dropdown heights as if the aircraft had suffered an engine failure at maximum takeoff weight.

The OEI training facility has two modes. In Training Flight Mode, derated engine power is available from both engines. In Training Idle Mode, the selected engine provides no power but is governed at 91% N2. If the main rotor droops to 91% or below, the selected engine begins to provide power, and 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 will provide power exactly as if an actual engine failure of the other engine had occurred, but to derated 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 in event of a real failure.

Rejected take-off procedure

The aircraft is flown in the VIP role by the private operator. Although Joint Aviation Requirement Operations 3 (JAR-OPS 3) applies only to commercial air transportation (helicopters), the operator in this case had decided that all takeoffs and landings with VIPs on board would comply with JAR-OPS 3 Performance Class 1.

Performance Class 1 operations are defined as operations in which, in the case of a critical power unit failure, the helicopter can either land on the rejected takeoff area, or safely continue the flight to an appropriate landing area, depending on when the failure occurs.

The vertical takeoff procedure that the crew were practising was developed by the aircraft manufacturer and was designed to permit Performance Class 1 operations at sites limited by obstacles. The Rotorcraft Flight Manual (RFM), Supplement 8, Part 1, describes the following procedure to be carried out for a vertical takeoff with a single engine failure before TDP followed by a rejection and vertical landing:

> *1. Sharply reduce collective to minimize ballooning*
>
> *2 As the aircraft altitude peaks, readjust collective to achieve 30 second power and allow rotor to droop to 104 to 106% Nr.*
>
> *3 Maintain position with cyclic and accept the descent rate at 104 to 106% Nr with the collective fixed. Do not attempt to adjust rate of descent prior to next step.*
>
> *4 At a low altitude when closure rate and altitude dictate that ground contact is imminent, apply collective at a rate and amount sufficient to cushion the landing. A slow, gradual collective input applied at excessive altitude must be avoided.*
>
> *5 After touchdown, neutralize cyclic and reduce collective to recover Nr to 100%.*

The helicopter manufacturer provided the investigation with flight test data obtained during the development of the above procedure and amplified the rationale for each element of the procedure:

Step 1, which requires the sharp reduction of collective, is designed to minimize the total height of the procedure and to reduce the loss of Nr following engine failure. The aircraft accelerates toward the ground from the apex of the manoeuvre. Generally, the maximum rate of descent achieved before touchdown depends on a combination of the maximum height achieved and the amount of power set on the remaining operative engine. Notwithstanding this sharp reduction of collective, Nr initially reduces and, from test data, the amount of droop seems to correlate closely with pilot reaction time. During flight test, an Nr droop of up to 7% was seen between Step 1 and Step 2.

The aim of Step 2 is to ensure that maximum power is applied to the main rotors by the fully operative engine. The S76C+ is fitted with Full Authority Digital Engine Control (FADEC), which effectively prevents engine limitations from being exceeded as a result of pilot input. Provided the power available exceeds the power required, the FADEC will maintain Nr at 106 to 108%. Thus the FADEC permits a degree of "carefree" engine handling for the pilot and Step 2 is designed to make use of this facility in setting the required power. The reapplication of collective after Step 1 is intended to demand power from the engine, to the point where the demand slightly exceeds the maximum power available, and the Nr reduces from the normal 106 to 108% to 104 to 106%. By using this technique, the pilot can be sure that full single engine power is applied by reference to only one indication (Nr), without having to spend undue time looking inside the cockpit during a period of high workload. Flight test data showed that test pilots delayed Step 2 slightly if Nr reduced below 104% at the beginning of the manoeuvre to allow the FADEC to increase the Nr to 104 to106%.

Step 3 ensures that maximum power remains applied for the entire descent to landing. Any attempt to adjust collective position may result either in less than the required amount of power being applied, and thus an increased rate of descent or, if the power demand is too great, a loss of Nr.

At Step 4, the collective is increased beyond the maximum power position for the operating engine and rotor rpm is allowed to reduce below 104 to 106%, as the rate of descent is decreased for landing. The RFM contains a warning against a slow, gradual collective input at excessive altitude in order to prevent a loss of Nr before landing is imminent. Flight test data showed that the elapsed time for the manoeuvre varied with the height of the TDP. Using a TDP of 100 feet, the time to touchdown from simulation of the engine failure was generally about 10 to12 seconds.

RFM Supplement 8, Part 2, Pilot Training Provisions, highlights "cautions and recommendations" during training of the manoeuvre. Particular emphasis is placed on rigid adherence to limitations and the procedures described in the manual, and the need for the instructor to remain poised to reselect TRAINING FLIGHT (dual engine training) on the OEI switch if the manoeuvre is not proceeding as desired.

The operator's standard operating procedure for conducting the above procedure requires the handling pilot to make the decision to reject the takeoff and to make a call of "REJECTING, CALL Nr". The handling pilot then concentrates exclusively on flying the manoeuvre, whilst the non-handling pilot looks inside the cockpit to ascertain the Nr and calls the reading aloud. The handling pilot makes collective adjustments in accordance with the RFM procedure to achieve the required Nr.

Tests and Research

In consultation with the aircraft manufacturer, it was concluded that the aircraft had responded as expected to the control inputs applied. The manufacturer also provided flight test evidence showing that, with the main rotor speed maintained at 105% (2% below the governed range), peak descent rates ranging between 800 and 1,200 feet per min had been observed.

The data from the incident was compared with that recorded during two other rejected takeoffs (RTOs) from 100 feet. One RTO was conducted immediately prior to the incident and the second was conducted as the last exercise of the training session following two RTOs from 40 feet.

In both cases the Nr, having initially drooped to 105% just after the simulated engine failure, increased back towards the governed range of 106 to 108%. More collective had been applied than in the incident with the result that higher (but not maximum available) single engine torque had been applied for the descent. Consequently, descent rates were reduced, but were still greater than those experienced during flight test.

Analysis

The incident occurred because a high rate of descent developed in a practice rejected vertical takeoff and the rate of descent was not sufficiently arrested to prevent a hard landing.

The aircraft weight was below the training procedure WAT limit and was within limits for the manoeuvre. Initial investigations centred on the possibility that the high rate of descent had developed because the aircraft entered a Vortex Ring condition. However, the FDR evidence showed that the aircraft was responding normally to collective input throughout the descent, which makes this possibility unlikely.

The RFM procedure prohibits carrying out the procedure in downwind conditions and the possibility that a tailwind developed during the training was considered. However, while the pressure gradient was about 70° to the left of the aircraft's heading, there is no evidence that a tailwind was present during the incident. Nevertheless, flight testing was carried out in headwinds averaging 2 kt, and the lack of headwind may have been partly responsible for rates of descent being greater than those experienced during flight testing.

The crew planned to move forward slightly in descent to provide the equivalent advantages of a headwind over the rotor blades. However, although forward movement is not part of the approved procedure, in practice little forward movement was achieved. It is not considered to have been a significant factor in this accident.

Analysis of the FDR data indicated that the maximum height of the accident manoeuvre was 119 feet, whilst similar manoeuvres, conducted during flight testing, had reached heights of over 130 feet. It is therefore unlikely that the high rate of descent was due to excessive ballooning. However, the operating engine was producing significantly less than the target torque for all three practices from 100 feet This power shortfall appears to be largely responsible for the greater than normal rate of descent (Figure 1) *(jpg 144kb)*.

The crew had a clear understanding of the rejected take-off procedure, but the correct power setting was not achieved. During all three practices from 100 feet, the Nr reduced to about 105% almost immediately after the handling pilot had lowered the collective, and took about two and a half seconds to increase back to 106 to108%. During the start of the manoeuvre, the training captain noted that 105% Nr had been achieved and, having satisfied himself that the power had been correctly set, he diverted his attention outside. He was not aware that the Nr had drooped to 105% because of the dynamics at the start of the manoeuvre rather than a reapplication of collective by the handling pilot. Moreover, with his attention focussed outside on achieving a safe landing, he was not aware that the Nr subsequently increased during the descent.

As non-handling pilot, the training captain was responsible for calling Nr, but as aircraft commander he was also responsible for the safety of the aircraft. The training captain's initial priority was therefore to ensure the correct Nr had been achieved, but thereafter he had to transfer his attention outside the cockpit to monitor the landing. Given that the procedure from the simulation of the engine failure to landing was about 6 seconds, there was very little time for the training captain to spend on either task. However, the manufacturer's test data indicates that with the correct power set, the descent time from simulated engine failure to landing would have increased significantly and the training captain would have had much more time to accomplish both tasks safely.

The training captain and the handling pilot were both very experienced pilots who had accomplished the accident manoeuvre successfully on many occasions previously, both by day and by night. It is therefore surprising that the abnormally high rates of descent generated were not recognised by the crew. However, the night visual cues available, whilst adequate for the exercise, were limited. It seems likely that the training captain diagnosed a symptom of the high rate of descent (the need for earlier collective movement to cushion the landing) rather than the fundamental cause.

RFM Supplement 8, Part 1, provides a concise list of actions to complete the manoeuvre, and the published procedure has been approved by the CAA. RFM Supplement 8, Part 2, Pilot Training Provisions, is not CAA Approved but provides amplifying detail. Part 2 does not mention the fact that Nr will droop at the beginning of the manoeuvre and that the amount of droop will depend, in part, on pilot reaction time. Furthermore, while the requirement to set and maintain the required power during the descent is described in Part 1, the technique for setting the power using indications of Nr, and the possible need to adjust the collective in descent, is not covered in Part 2.

As a result of this accident the operator has carried out an in depth risk analysis of all its training procedures with the result that Clear Area, Vertical and Short Field OEI rejected takeoff practice will be carried out only in the simulator. Vertical procedure practice in the aircraft will be subject to revised wind speed limitations and will be carried out in the all engines operating training mode and recovered to level flight by 10 feet agl. In addition, the operator intends to develop, with the manufacturer, an amplification of RFM Supplement 8, Part 2, to place greater emphasis on the technique for setting and monitoring power during the manoeuvre.