

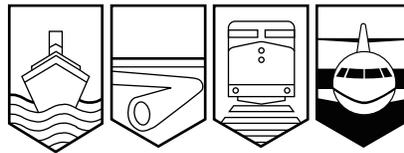
Transportation Safety Board
of Canada



Bureau de la sécurité des transports
du Canada

AVIATION INVESTIGATION REPORT

A03P0247



LOSS OF ENGINE POWER – COLLISION WITH TERRAIN

GEMINI HELICOPTERS INC.
BELL 204B (HELICOPTER) C-GEAP
BONAPARTE LAKE, BRITISH COLUMBIA
17 AUGUST 2003

Canada

The Transportation Safety Board of Canada (TSB) investigated this occurrence for the purpose of advancing transportation safety. It is not the function of the Board to assign fault or determine civil or criminal liability.

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Summary

The Bell 204B helicopter (registration C-GEAP, serial number 2063) operated by Gemini Helicopters Inc. was involved in forest fire suppression at Bonaparte Lake, British Columbia. At about 1105 Pacific daylight time, the helicopter departed a staging site, eastbound, slinging an empty water bucket on a 100-foot longline for the first mission of the day. Shortly after take-off, the helicopter emitted a high-pitched, oscillating sound. The flight path and behaviour of the helicopter were normal as it went out of view over some trees. Immediately thereafter, there was the pronounced sound of main-rotor blade slap, followed by the sounds of impact with the trees. The helicopter struck the ground just short of reaching a small clearing adjacent to a fire road about $\frac{1}{4}$ nautical mile southeast of the staging site. A post-impact fire ensued, which destroyed the helicopter cabin area and melted the transmission casing and pylon structure. The main driveshaft assembly remained attached to the engine and transmission input quill assembly. The water bucket was found in a tree, detached from the longline, on the approach to the accident site. The longline was wrapped around another tree and lay in a direct line to the helicopter; other than the metal parts, the top 15 feet of the artificial fabric line was burned away. British Columbia Forest Service crews attended the site and extinguished the fire. The pilot was fatally injured.

1.0 *Factual Information*

1.1 *Operations Background*

On Wednesday, 13 August 2003,¹ the occurrence pilot completed the daily flights at the Bonaparte Lake site and returned to Kamloops, British Columbia, where the engine and transmission were to be changed; both were time expired and due for an overhaul. The total airframe time was 11 538.8 hours. On 13 and 14 August, the engine and transmission assemblies were changed by company maintenance personnel. Honeywell (Lycoming) engine assembly model T5311B, part number 1-000-080-11, serial number LE-08228, was installed. This engine had a total time since new of 7398.1 hours and had been overhauled to a zero-time condition. Bell Helicopter Textron transmission assembly part number 204-040-009-087, serial number B12-601, was also installed. This transmission had a total time since new of 6808.2 hours and 396.5 hours since overhaul.

The new components were run for the first time on the evening of 14 August, and the following morning, an engine on-ground power check (partial power) was performed. The power plant was operating at 1.4 per cent below the calculated N1² rpm required, and N1 take-off trim adjustment of $\frac{3}{8}$ of a turn was required to increase N1 to the calculated figure. (Consultations with industry personnel indicate that N1 take-off trim adjustments are not an unusual requirement.) An entry was made in the aircraft journey log indicating that all work done was certified, pending a satisfactory test flight, including an N1 topping check and a power check. A test flight was performed and engine operating parameters relevant to the power check were recorded in the aircraft journey log on 15 August 2003. The data was plotted against the engine operation and functional-check charts, and results were also entered in the journey log. It was recorded that the engine was operating at an N1 speed of 2.3 per cent below the allowable limit of 93.3 per cent and an exhaust gas temperature (EGT) of 60°C below the allowable limit of 590°C. When the power-check calculations were reviewed during the investigation, it was determined that both were correct. Maintenance logs or personal notes did not record any results to verify the N1 topping speed after the engine was installed into the helicopter before or after the N1 adjustments. Such a record is not required by regulation. The engine power check recorded in the journey log provides a means of estimating the engine power output and tracking its performance. An N1 topping check is required to confirm that the engine achieves the rated performance without exceeding its engine data plate placard limit. The pilot signed off the journey log, approving the aircraft for further flight.

An engine vibration check was completed at the overhaul facility; however, a vibration check was not accomplished prior to returning the aircraft to service following the engine's installation in the helicopter. The Honeywell Lycoming engine maintenance manual specifies that a vibration check shall be performed following an engine installation. Conducting a vibration check provides the opportunity to verify that the engine-to-transmission alignment is correct and to detect any engine damage that could be the result of shipping or mishandling.

¹ All times are Pacific daylight time (Coordinated Universal Time minus seven hours).

² N1 refers to the gas producer rotational speed and is indicated in percentage of designed rpm.

The helicopter resumed work at the Bonaparte Lake site. After about 20 minutes of working, the pilot relayed a message to the maintenance crew in Kamloops, requesting that the engine vibration test equipment be kept. Another 30 minutes later, the pilot reported to the British Columbia Forest Service office that the helicopter was unserviceable and he returned to Kamloops. The pilot reported a buzzing cowling and that the engine lacked sufficient power to lift the load, resulting in the main-rotor rpm drooping.³ The vibration test kit (Chadwick-Helmuth 7460A) was then installed on the engine and a flight test was carried out. The vibration check indicated that the engine was operating within specifications. The failure to perform a vibration check at initial installation, therefore, had no bearing on the subject failure, since a vibration check was conducted with no problems being indicated approximately 50 flying minutes after engine installation. Subsequent to the test flight, the power and drooping issues were addressed by a further small increase in the N1 take-off trim setting. No record of an N1 topping check could be provided. The next morning (16 August), the helicopter returned to the staging site and the pilot recorded 8.8 hours of air time for the day, during which the pilot made several reports to indicate that operations were normal. No further adjustments were made to the engine or transmission when the helicopter returned to Kamloops in the evening. The helicopter was refuelled at Kamloops with 563 litres of Jet A (maximum capacity of 915 litres).

It is known that the N1 speed was established to be 97.6 per cent at the overhaul facility, and this was the placard setting at which the engine produced its full-rated horsepower under International Standard Atmosphere conditions at sea level. By providing a physical restriction to fuel flow, the take-off trim setting is the N1 overspeed protection device. It is possible to operate the engine at higher N1 speeds, approaching the compressor overspeed limit, and it appears to produce all desirable effects; that is, more power, while apparently remaining within the allowable engine torque and EGT parameters (see text box). Without the confirmation of an N1 topping check after an adjustment, it is not

The U.S. National Transportation Safety Board (NTSB) investigation report SEA85FA134 presents the following information retrieved from the manufacturer's T53 training manual:

There is a common misunderstanding that it is safe to "jack up" the Takeoff Trimmer to permit N1 speeds approaching the overspeed limit of the compressor, and thereafter fly the aircraft by monitoring EGT and Torquemeter Pressure. The use of this procedure allows the engine to produce higher N1 speeds and greater torque on a hot day, but the problem is that it also results in Turbine Inlet Temperatures (T5) higher than specification with consequential damage to components in the hot end. The Exhaust Gas Temperature (T9) measured on the T53 Engine is not necessarily proportional to T5, and on a hot day it is possible to have T9 within limits while T5 is unknowingly too high. The manufacturer's Maximum Available Horsepower limits are designed to keep T5 within specifications by reducing the available torque as the OAT [outside air temperature] increases. This is accomplished by keeping the Takeoff Trimmer adjusted to specification. If the trimmer is adjusted above specification, excessive T5 temperatures will result in degradation of the Hot End components when the Engine is operating in hot weather.

It is also noted that this procedure results in an increased risk of destructive compressor stalls (NTSB investigation FTW85FA188).

³ "Drooping" is a reduction of the main-rotor rpm and mechanically linked power turbine (N2), because the engine cannot sustain the existing load. When the engine is automatically governed, the onset of drooping indicates that the N1 gas producer assembly has topped out (reached maximum fuel flow) and the engine cannot produce any more power at the current N1 take-off trim setting.

known whether the N1 speed is within specifications. After the N1 was adjusted the last time, the pilot operated the helicopter the following day and made several reports indicating that operations were normal, which would suggest that the change appeared to be beneficial. However, if the N1 was above specification, excessive T5 temperatures could result in a degradation of the hot section components.

1.2 *Pilot Information*

The pilot, experienced and familiar with the type of operation being conducted, had been hired by Gemini Helicopters Inc. on a temporary basis to provide relief for the pilot normally assigned to the helicopter. He possessed a valid Canadian airline transport pilot licence – helicopter, and had completed a pilot proficiency check on the Bell 204 in June 2003. Records indicate that the pilot had accumulated about 7500 hours of total flight time, of which 200 hours had been flown on Bell 204 helicopters in the previous 90 days. He had flown C-GEAP during the last two weeks of June and then again beginning on 13 August 2003.

1.3 *Meteorological Information*

The staging site was located at an elevation of about 4500 feet above sea level (asl) in an area of rolling hills. The vegetation consisted of undergrowth in a primarily spruce forest. The prevailing weather conditions were sunny, hot and dry. At the time of the accident, a British Columbia Forest Service weather site, 14 nautical miles to the southwest at an elevation of 3839 feet asl, recorded a temperature of 20°C with variable winds that reached a maximum speed of 8 knots throughout the day. A normal lapse rate would yield a temperature at the elevation of the staging site of about 19°C. An altimeter setting of 30.04 inches of mercury was recorded at the Kamloops Airport, 33 nautical miles to the south (elevation 1133 feet asl). At an average working altitude of 4500 feet asl, the weather conditions existing at the time equate to a density altitude of about 5900 feet and a pressure altitude of about 4620 feet. The previous day was about 5° warmer, with an additional 3 knots of wind.

1.4 *Aircraft Information*

1.4.1 *General*

The Bell 204B helicopter was equipped with a single Honeywell (Lycoming) T5311B free-turbine engine, with a design limit of 1100 shaft horsepower. At the time of the accident, the helicopter had flown for about 10.9 hours since the engine and transmission were installed.

The helicopter was not equipped with a flight data recorder or a cockpit voice recorder, nor were they required by regulation.

1.4.2 *Aircraft Performance*

The Bell 204B flight manual indicates that, under the ambient conditions that existed, the helicopter would hover out-of-ground effect at a gross weight of 3484 kilograms (kg). The estimated weight of the helicopter at the time of the accident was 3548 kg. The collapsible Bambi® water bucket had a maximum capacity of 1225 litres (1225 kg) and a maximum gross

weight of 1280 kg. To restrict the capacity, the bucket was equipped with a circumferential strap, which could be manually cinched. The bucket, as found, was cinched to 80 per cent capacity (980 litres or 980 kg). The helicopter gross take-off weight for external load operations was 4309 kg. The centre of gravity was not considered to have been a factor.

1.4.3 External Load Operations

The accident helicopter was equipped with a vertical reference kit that allowed for single-pilot operation from the left seat for longlining operations. Part of the vertical reference kit was a third foot pedal that provided mechanical release capability for the external cargo hook on the belly.

A 100-foot braided fabric longline was in use and was equipped with an electrically operated (remote) hook assembly at the lower end, to which the water bucket was attached. Enclosed within the braid of the line was a pair of electrical wires to supply electrical power to operate either the remote hook or the bucket water-release mechanism. The wires were connected to the bucket water-release mechanism, thereby intentionally disarming the remote hook since it was not required for the operation or emergency purposes. Attached to the outside of the longline was a standard electrical extension cord, which would supply electrical power from a control box on the console between the pilot seats to operate a foam injection pump within the water bucket. The bucket was not equipped with such a pump and, therefore, this cord was not serving any purpose.

Site examination of the external load system revealed that the water bucket was detached from the remote hook. There was no apparent damage to the remote hook, and subsequent testing determined that it could be operated manually and electrically. The control head of the bucket assembly with an attached shackle also remained intact and appeared to be undamaged.

In general, helicopters have critical flight regimes from which the probability of establishing a successful autorotation is extremely low.⁴ The Bell 204B Owner's Manual, Limitations section, specifies these conditions in its height and velocity diagram.⁵ The height and velocity diagram directs pilots to avoid operating under specified conditions of altitude and airspeed. However, this direction does not constitute a regulatory limitation for external load operations. Helicopters engaged in water-bucketing (external cargo) operations routinely operate under these critical conditions.

Similar to other medium and large helicopters, there are five switches on the Bell 204 cyclic control grip; however, the function of each switch can vary from one helicopter to another. Canadian Aviation Regulations (CARs) 527.865 and 529.865 require a primary quick-release system for the external cargo hook. However, neither the regulations nor standards specify that a particular switch must be assigned to the quick-release function for the external cargo hook. Therefore, there is no common design among manufacturers and operators to configure the function of these switches to suit their types of external load operations. Due to a previous

⁴ G.H. Saunders, *Dynamics of Helicopter Flight* (New York: John Wiley & Sons, 1975).

⁵ Bell 204B Owner's Manual, Section 1, Limitations.

pilot's preference, Gemini Helicopters Inc. had reconfigured three switches on the grip: the middle switch (activated by the thumb) operated the external cargo release, while either of the other two switches (the bottom switch activated by the little finger or the top conical switch, also operated by the thumb) operated the bucket water-release mechanism.

Most of the pilot's experience consisted of longline operations, and records of the pilot's flight time indicate that at least 2700 hours of his most recent experience involved the use of cyclic grip configurations in which the bottom switch, operated by the little finger of the pilot's right hand, was used to release the external cargo hook. This helicopter was configured differently. Although the pilot knew that the external cargo hook release switch position had been changed, and he had used this system for two weeks in June and again for two days in August prior to the accident, it was not what he was accustomed to.

Studies in human behaviour suggest that, amongst other variables, relative and finite amounts of practice influence which automatic behaviour occurs in an emergency situation; the more practised behaviour will be the default behaviour. The studies conclude that a pilot would require practice with a new switch configuration for 30 days, or 85 hours or 1000 repetitions or more than with the known configuration, for it to become an automatic behaviour. With less practice, it would be difficult for the pilot to automatically and correctly select the appropriate switch to jettison the external load from the helicopter.⁶

The longline would normally be released from the external cargo hook in an emergency situation; however, the success of such an attempt may be hindered by the time available due to factors such as altitude, terrain, type of emergency and pilot familiarity with the specific release systems. In this occurrence, the longline was not released and it became entangled in a tree during the attempted emergency landing. It could not be determined what action the pilot took regarding the longline, nor was it possible to confirm the serviceability of either quick-release system. It was learned that the pilot's normal practice was to operate the helicopter with the external cargo hook switch in the armed position; however, damage prevented investigators from determining the position of this switch. The Transportation Safety Board of Canada (TSB) has identified reported occurrences where pilots have made errors in external-load release activations. Examples include the following:

A02P0251 – Elaho Valley, Squamish, British Columbia, MD500D, 09 October 2002

A00W0020 – Robb Seismic Camp, Alberta, Bell 205A, 22 January 2000

A87P0025 – Gabriola Island, British Columbia, Bell 206, 15 May 1987

⁶ W. James, *Principles of Psychology* (New York: Holt, 1890); E. Spelke, W. Hirst and U. Neisser, "Skills of Divided Attention," *Cognition*, 4 (1976) pp. 215–230; R. M. Shiffrin and W. Schneider, "Controlled and Automatic Human Information Processing: II. Perceptual Learning, Automatic Attending and a General Theory," *Psychological Review*, 84(2) (1977), pp. 127–190.

1.5 *Wreckage and Impact Information*

1.5.1 *General*

The final heading of the helicopter was approximately 160° greater than the departure heading. The bucket became detached from the longline at the remote hook before impact; the longline with the remote hook remained attached to the helicopter as it approached the road. About 80 feet from the bucket, in the direction of travel, the end of the longline with the remote hook was found wrapped around another tree that had broken off above, but the trunk remained standing. The longline lay in a direct line from this tree to the helicopter.

The helicopter was found lying on its left side with all components of the airframe and thrust system present and in the correct orientation to each other except for the horizontal stabilizers, which were nearby but separated from the tail boom. The tail boom was adjacent to, but separated from, the main fuselage in the vicinity of the tail boom attachment point. The tail-rotor assembly, including the 90° gearbox, was intact and in place on the vertical stabilizer, and the leading edges of both blades were devoid of impact damage. The tail-rotor driveshaft exhibited a torsion type of fracture most of the way around the circumference, a short distance ahead of the 42° gearbox; both gearboxes contained oil and the pitch-link chain was intact. The main-rotor blades lay in a fore and aft orientation to the fuselage; the blades were bent and broken downward, but the leading edges were devoid of impact damage. The main-rotor control assembly lay in a normal orientation to the rest of the aircraft; however, the main-rotor mast was detached from the transmission. The transmission casing was completely melted, leaving the internal gears exposed. The transmission input quill was resting on molten transmission debris but remained attached to the engine by the main driveshaft. The input pinion gear was not broken. The aircraft cabin was severely damaged by the post-impact fire and little remained of the instrument or electrical panels.

1.5.2 *Engine Examination*

Post-accident examination of the engine revealed that there was virtually no damage to the power turbine (PT) section, accessory gearbox or reduction gearbox of the engine; however, there was extensive damage to the gas producer section. The gas producer section consists primarily of five axial compressor disks (each with a spacer behind it) plus a single-stage centrifugal compressor, all driven by a single-stage compressor turbine (CT) at the exit of the combustion chamber. Surrounding each spacer, between the blades of sequential axial disks, is a set of stationary stator vanes attached to the outer casing of the compressor.

During the engine teardown, it was observed that all blades on the fourth and fifth axial disks were fractured at or near the blade root. Twenty blade roots and 13 disk posts of the fourth-stage disk were broken from the core of the disk itself. The debris, including the 20 blade roots, was found piled up in the lower compressor case, half at the location of the fourth- and fifth-stage axial disks.

Once the physical debris was removed from the compressor, the compressor rotor, including the compressor turbine, was able to rotate. The blade tips of the first three axial disks exhibited smearing of metal in both directions; the smearing damage was more pronounced with each

stage from front to rear. The first, second, third and fourth stators and the exit guide vanes all had localized scoring, metal discoloration, and deformation on the outer portion of the forward and aft lip where contact was made with the spacers. Damage to the stators varied from localized cracking at the vane roots of the second stator to extensive gouging, tearing and forward deformation at the exit guide vane. All five spacers exhibited scoring damage where contact had been made between the spacers and the lip of the stationary stator vane assemblies. The aft end of the fourth-stage spacer (between the fourth and fifth axial disks) exhibited the greatest damage and had a score mark that was worn right through the spacer for about one-third of the circumference.

The last stage of the compressor is the centrifugal impeller. Although there was significant scoring on the inlet of the impeller housing, damage to the impeller blades was primarily to the leading edges with only localized nicks and scoring further aft. The impeller housing (at the forward side of the impeller) exhibited depressions that corresponded to the shape of the impeller blades. Since there was no indication of smearing at the depressions, the TSB Engineering Laboratory concluded that the rotor assembly was likely not rotating at the time of ground impact.

Run-out measurements of the third-, fourth- and fifth-stage spacers and the blade tips for the first three axial stages were taken before disassembly of the compressor rotor (the measuring device could not reach the first- and second-stage spacers). When plotted on a polar graph, the measurements of the blade tips displayed oval or elliptical shapes. The ovalized shapes became progressively more pronounced from the first stage to the third stage. Graphical plots of the measurements of the aft three spacers displayed round shapes centred away from the main axis of the rotor, with the maximum divergence at the fourth-stage spacer. The TSB Engineering Laboratory examined the disassembled compressor rotor components and confirmed that the blades on the first three axial stages varied in length around the circumference of each component and from component to component. The TSB Engineering Laboratory also concluded that there was no indication of a foreign object entering the compressor. All of the disk and blade fracture surfaces that were not smeared exhibited signs of overload failure; the balance of the fracture surfaces showed extensive smearing such that no conclusion could be reached with respect to the mode of failure. However, the condition of the fracture surfaces and the numerous pieces of blade material indicates that the rotor assembly continued to rotate for a period of time after the initial failure.

At the discharge end of the combustion chamber, the hot gases pass through a stationary set of nozzle guide vanes (CT nozzle), which direct the gases onto the blades of the compressor turbine. After passing through the CT blades, the gases pass through another set of stationary nozzle guide vanes (PT nozzle) and then through the PT blades before exiting the engine. The distance between the CT and PT disks is approximately 5 cm, with the PT nozzle occupying most of this space. It was observed that about one-half the CT nozzle vanes exhibited uneven trailing-edge damage indicative of melting. The ends and trailing edges of all CT blades exhibited the same type of damage and were reduced in size by approximately 30 per cent. The PT nozzle exhibited minor damage on the leading edges of the vanes, and there was virtually no damage to the PT blades. The compressor rotor assembly is supported at each end by a bearing; there were no indications of damage to either bearing.

The CT disk (as found) was dynamically checked for balance and was found to be beyond specifications. Examinations for other indications of a CT wobble, which may have migrated forward through the number two bearing and applied an external bending force to the rigid axis of rotation of the compressor rotor, were carried out. Signs to support a progression of damage in this direction were not found. Such signs could be rub damage to the case surrounding the CT disk, damage to the number two bearing, contact between the hollow tail shaft of the compressor rotor and the power shaft rotating inside of it (in the opposite direction), or thermal damage to the PT nozzle and blades, suggesting a sustained over-temperature condition.

The compressor rotor is a “stacked-up” assembly of several parts for which the manufacturer established a specific procedure detailed in the overhaul manual. Approved repair and overhaul facilities perform this work; Cappsco International Corp., which overhauled the engine, is approved by the U.S. Federal Aviation Administration (FAA) to complete this work and is subject to regular FAA audits. Regulatory requirements exist in the United States for maintenance facilities to administer quality control procedures and to provide qualified personnel.⁷

Records and procedures used for the overhaul work performed were reviewed. It was found that, during the compressor rotor assembly build-up procedure, the assembly was stacked vertically and began at the aft end. Once the second-stage disk was set in place, the power shaft and internal sleeve were installed, then the heated first-stage spacer was set in place, followed by the placement of the first-stage disk. The bolt holes in the first-stage disk must be aligned with bolt holes in the internal sleeve, and the manufacturer provides two guide pins to thread into the internal sleeve bolt holes to aid in aligning these holes.⁸ However, a hand-held punch was used for this task. This punch was then used in the attempt to rotate both pieces uniformly to align the internal tangs and slots of the first- and second-stage disks, which were obstructed from view by the sleeve. The result was that the tangs and slots of the first- and second-stage compressor disks were not aligned and did not mate correctly within the first-stage spacer. Indentations on the second-stage compressor disk (new part) indicated that at least two assembly attempts had been made to mate the first- and second-stage compressor disks while their respective slots and tangs were misaligned. In the process, one top corner of each tang was broken away. During the final compression, a piece of the removed material was crushed between the two disks to the dimension of the space remaining when both axial disks were pressed against the outer circumferences of the first-stage spacer. The TSB Engineering Laboratory found similar damage to the rear mating surface of the fifth-stage disk alignment slots and the impeller alignment tangs (also a new part). Prior to installing the sleeve, all tangs and slots could be inspected for proper engagement. Since the fit between the spacers and the disks is tight, the spacers are pre-heated to ease the assembly, placing some urgency on completing this task in a timely manner.

The assembled compressor rotor assembly is then compressed in a hydraulic press. Three compression and release cycles are specified prior to applying the specified torque to the

⁷ (U.S.) Federal Aviation Regulations, Part 145, Repair Stations, Section 145.151.

⁸ Lycoming T5311-3, *Overhaul Manual*, chapter 72-30-31, “Assembly of Compressor Rotor Assembly A,” (8)(9)(10), p. 502.

10 retainer bolts in the first-stage disk.⁹ Only one compression load was applied. The specific reason for three compression cycles or the consequences of using other than three cycles were not provided by the manufacturer.

The length measurement of the compressor rotor assembly referred to in the overhaul manual as Dimension "A" is a comparison of three measurements taken around the circumference during the final compression cycle in the hydraulic press and again after removal from the press to determine that the plane of the first-stage disk is perpendicular to the axis of the assembly. Dimension "A," taken after release from the press, is required to be recorded.¹⁰ This dimension was not taken while the rotor assembly was in the hydraulic press nor after it was released from the press. Another length dimension taken between the number one and number two bearing shoulders was taken and recorded, and was determined to be within specification. It was noted during the investigation that, when the dimensions of all applicable parts are summed up, the dimension between the number one and number two bearing shoulders falls within the specification without any compression of the assembly.

The compressor rotor assembly was balanced prior to installation in the engine, and subsequent vibration checks, both in a test cell and during a test flight after installation in the helicopter, did not identify anomalies.

Although the engine was not completely destroyed by the post-impact fire, it was exposed to enough heat to deform outer surfaces and to burn hoses and wiring bundles. It was decided that there was little chance of the interior gaskets and seals of the fuel control unit (FCU) remaining intact; therefore, the FCU was not tested or dismantled for examination.

The position of the manual override (emergency) solenoid on the FCU, which can be selected by the pilot to bypass the power turbine governor (PTG) and control the fuel flow manually, was determined by X-ray to be in the automatic/normal position.

The air supplied by the compressor provides for cooling as well as for combustion; therefore, reduced airflow resulting from any anomaly within the compressor itself may produce increased internal engine temperatures. As previously described, the compressor rotor blades exhibited indications of rub (contact between a rotor and its stator). Rub may typically be caused by mass imbalance, turbine or compressor blade fracture, defective bearings and/or seals, or by rotor misalignment, either thermal or mechanical.¹¹

The transmission was also a new installation in the helicopter, and maintenance records were obtained regarding the overhaul and subsequent repair prior to installation. A detailed

⁹ Lycoming T5311-3, *Overhaul Manual*, chapter 72-30-31, "Assembly of Compressor Rotor Assembly B," (6A), p. 502B.

¹⁰ Lycoming T5311-3, *Overhaul Manual*, chapter 72-30-31, "Assembly of Compressor Rotor Assembly B," (11), p. 502B.

¹¹ S. Edwards, A.W. Lees and M.I. Friswell, "The Influence of Torsion on Rotor/Stator Contact in Rotating Machinery," *Journal of Sound and Vibration*, 225 (4), (1999) pp. 767-778 (article No. jsvi.1999.2302).

teardown examination of the transmission or any part of the drive train was not completed due to their condition and the fact that a drive train malfunction, in this model of helicopter, would not result in self-destruction of the power plant gas generator section.

1.6 *Fire*

The source of ignition of the post-impact fire remains undetermined. The fuel tanks in the Bell 204 are located at the lower-rear corners of the cabin structure; C-GEAP was fitted with large fuel tanks with a capacity of 915 litres. The helicopter had been refuelled to capacity on the previous evening with Jet A grade turbine fuel. At the time of the accident, there would have been about 810 litres of fuel on board.

2.0 *Analysis*

2.1 *General*

The action of the pilot to turn around and proceed toward the fire road indicates that he likely detected a problem and was returning to the staging site, but did not have time to reach the road. Given the flight path, it is likely that the engine failure began as a rapid and progressive deterioration prior to the ultimate failure of the compressor assembly. The combination of altitude and terrain features placed the helicopter in a flight regime from which the probability of a successful autorotation was minimal. The snagging of the bucket and then the trailing longline on a tree had a further negative effect on the pilot's ability to complete a successful emergency landing. The pilot's reaction to these events may provide an explanation for the loss of rotor rpm. As neither the helicopter's performance nor the drive train was considered to be a factor in the accident, this analysis focuses on the engine power loss and the reason the longline remained attached to the helicopter.

2.2 *Engine Power Loss*

2.2.1 *General*

The results of the engine teardown indicated that the following two events occurred within the gas generator section: excessive temperature at the compressor turbine, and contact between the compressor rotor and stator assemblies.

2.2.2 *Excessive Turbine Temperature*

The pilot report that the N2 was drooping indicated that the engine was reaching the maximum fuel flow allowed through the N1 take-off trim setting. Subsequently, the N1 take-off trim on the FCU was further increased by a small amount. Since the weight of the helicopter with the loaded bucket exceeded the maximum hover-out-of-ground-effect weight for the conditions, effective piloting technique in combination with as much engine power as possible would have been required to lift the loaded bucket out of the lake. While a higher-than-permitted FCU take-off trim setting would not cause the gas generator to exceed the allowable limit, it also would not provide protection against an overspeed¹² due to other reasons, such as a high power demand. Because the helicopter was lifting better after the final adjustment to the N1 take-off trim and the trim was adjusted at least twice since engine installation in the helicopter, it is possible that the engine was then being operated above the N1 placarded limit. If the adjustment was too high, it is a possibility that the engine was operating within the correct EGT range, but in the range where internal engine temperatures were unknowingly high, resulting in an increased risk of degradation of the hot section components.

¹²

The fuel trim setting on the FCU is an overspeed protection device.

Since the PT blades and even the PT nozzle, immediately behind the CT, did not receive the thermal damage exhibited by the CT blades, it can be concluded that a surge in temperature occurred, but the excessive temperature was not sustained long enough to cause melting of the PT nozzle and blades before the engine flamed out. Since no N1 topping adjustments were made for about nine hours of operation prior to the accident, it is unlikely that an excessive N1 trim setting could have produced the sudden surge in temperature exhibited. However, when the degradation of the compressor resulted in the PTG increasing the fuel flow, any damage occurring due to an excessive temperature condition would likely have been accelerated by a higher-than-normal fuel flow.

2.2.3 *Compressor Rotor Contact*

The TSB Engineering Laboratory was tasked to explain the elliptical shapes of the compressor blade tip plots (see section 1.5.2, paragraph 5) and, in summary, provided the following:

The components that make up the rotor assembly all have a circular shape and are designed to rotate about their geometric centre (axis of rotation). A critical design element of any high speed rotating assembly is the balancing of the individual components and of the complete assembly. In a balanced condition, the rotor's centre of mass (mass centreline) is the same as the rotor's axis of rotation. An unbalanced condition is caused by the displacement of the mass centreline from the axis of rotation through the addition or loss of material (mass). This imbalance results in centrifugal forces that cause the assembly to wobble and may result in contact with the stationary component. The results of this contact could be as minimal as blade tip rub (smearing of the blade tip) or as extensive as complete destruction. Since the rotor was dynamically balanced and successful vibration checks were carried out on the engine at the overhaul facility, and again after installation into the helicopter, it is concluded that the rotor assembly's mass centreline was the same as its axis of rotation. The elliptical shape of the blade tip plots was due to the differences in lengths of the blades and likely due to a subsequent misalignment in the rotor assembly.

The damage found within the compressor rotor could only have occurred during the overhaul, and there were known deviations from the specified overhaul procedure. Therefore, the Engineering Laboratory also examined the rotor components to determine whether incomplete seating during assembly may have resulted in seating taking place during operation, causing a loss of torque on the retainer bolts and allowing the assembly to flex and wobble. The Engineering Laboratory reported that:

. . . if the screws had subsequently lost their torque during engine operation, then the rotor components would no longer be held in compression, and it would be reasonable to expect relative movement between the adjoining components. Movement between adjoining components should have manifested into signs of fretting on their mating surfaces, but visual microscopic examinations carried out at the Engineering Branch did not identify any signs of fretting on any of the mating surfaces nor on any of the ten screws.

Since the compressor rotor assembly was balanced prior to installation in the engine and subsequent vibration checks did not identify anomalies, it is concluded that the crushed piece of material found between the first and second compressor disks did not affect the final dimension or alignment of the rotor assembly. The ovalized shape is indicative of the rotor assembly rotating in an unbalanced condition. Each time contact occurred, the centre of mass of the rotor changed, resulting in rotation about a new mass centreline, exacerbating the situation. No conclusion could be reached with respect to the mode of failure of the smeared blade fracture surfaces. It is possible that a progressive or fatigue type of failure may have existed, but none was found.

The summary of all information gathered leads to the conclusion that, for undetermined reasons, an imbalance developed within the compressor rotor during engine operation. This resulted in a wobble and subsequent contact between the rotor assembly and the surrounding stationary components. In combination, any disturbance to the airflow and any friction slowing the compressor rotor resulted in reduced airflow to the combustion chamber, thereby enriching the fuel to air mixture and increasing the temperature at the CT nozzle and disk. A loss of compressor efficiency resulted in a loss of N2 (PT and main rotor speed), which triggered the PTG to increase the fuel flow (increase the compressor speed toward the topping limit) to maintain the N2 at the selected speed (100 per cent), thus further increasing the temperature at the CT nozzle vanes and CT disk blades to the melting point. If the compressor was operating at N1 speeds in excess of the placard limit, this process would likely have been accelerated. In addition, compressor blade tip clearance may also have been reduced, thus increasing the risk of contact between rotating and stationary components. When the blade contact became severe enough, fourth- or fifth-stage compressor blades began to break due to overload, resulting in the destruction of all fourth- and fifth-stage blades. This resulted in the total failure of the engine before the PT nozzle and blades began to melt.

2.3 *External Load Operations*

The electrical function of the remote hook on the longline was intentionally disabled; therefore, the bucket could not have been released from the longline by the pilot. Discussion and demonstrations show that it is possible to twist a shackle out of the hook and it was concluded that, since there was no damage to the remote hook or the bucket control head and shackle, this was the most likely explanation for the detachment of the bucket when it contacted the trees.

The location of the external cargo release switch varies on different helicopters and with different operators. This results in a situation where a pilot, when moving from one helicopter or operator to another, is not accustomed to the switch location. In emergency situations, a pilot may not be able to quickly and instinctively activate the release switch.

In the accident helicopter, the switch position on the cyclic control grip was not what the pilot was accustomed to. It is highly likely that the pilot had yet to change his automatic behaviour and activate the external cargo release switch in the "new" location in an emergency. Therefore, it is probable that the pilot's action during the emergency did not activate the external cargo hook release mechanism and, rather, that the trailing longline snagged a tree while the helicopter was still airborne. This factor was an additional complication to the survivability

aspects of this accident; it could not be speculated whether items such as the pilot's safety harness or seat, or the aircraft's vulnerability to impact forces or post-impact fire would have permitted the pilot to survive the impact.

The designation of a specified switch location for the external cargo release is not required by regulation; hence, many variations present a risk of unsuccessful or inadvertent release. A backup quick-release method is also required by regulation. The foot pedal release installed in the accident helicopter was an approved system; however, its effectiveness is reduced because it requires the pilot to take one foot off of a primary flight control in an emergency. In TSB investigation A93W0159, it was determined that the pilot could not operate the foot pedal due to the uncontrolled behaviour of the helicopter.

The following TSB Engineering Laboratory report was completed:

LP 111/2003 – Engine Analysis

This report is available upon request from the Transportation Safety Board of Canada.

3.0 *Conclusions*

3.1 *Findings as to Causes and Contributing Factors*

1. An imbalance of the engine compressor rotor assembly developed during the operation of the engine, resulting in contact between the rotor and stator assemblies. The contact led to the destruction of the compressor rotor assembly and engine failure. No conclusion could be reached with respect to the mode of failure that caused the imbalance.
2. The combination of altitude, terrain features and the trailing longline negatively affected the pilot's ability to complete a successful emergency landing in autorotation.

3.2 *Findings as to Risk*

1. Some procedures used in the engine overhaul process were not in accordance with the manufacturer's overhaul manual; failure to comply with the manufacturer's instructions could compromise the integrity of the assembly and result in failure.
2. Field adjustments to the engine fuel control take-off trim without the confirmation of an N1 topping check for accuracy introduces a risk of frequent or continuous operations at gas generator speeds and internal temperatures beyond established limits.
3. An inconsistent placement of the external cargo release switch increases the risk of pilot confusion during an emergency when trying to activate the external cargo hook-release mechanism, possibly complicating an emergency landing.
4. The foot pedal backup quick release is an approved system. However, its effectiveness is reduced because it requires the pilot to take one foot off of a primary flight control in an emergency.

4.0 *Safety Action Taken*

On 09 December 2003, a Federal Aviation Administration (FAA) inspection of Cappsco International facilities and procedures was conducted. It was determined by the FAA that, at the time of the inspection, the inspectors “are confident that Cappsco International has the data, experience and knowledge to properly overhaul the engines for which they are rated.”

All Canadian operators of the T5311B engine were advised of the safety concerns identified during the overhaul process at Cappsco International facilities.

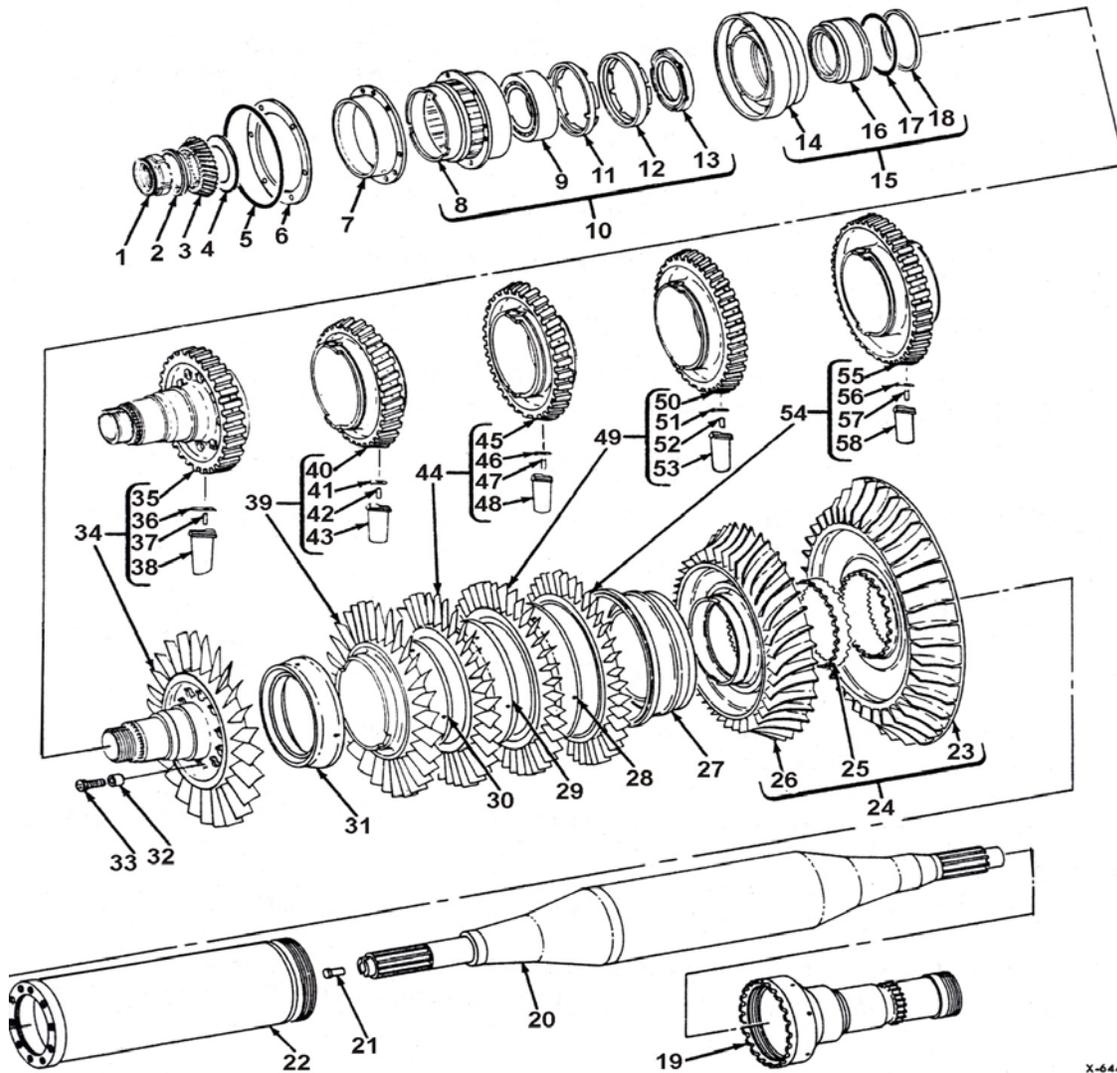
Gemini Helicopters Inc. has standardized the cyclic grips in all of its aircraft (excluding the Robinson 44s, which are incompatible for such a modification) so that the switches are the same in each type. It has also put the emergency (manual) release on the collective in its Eurocopter AS350s and is searching for Supplemental Type Certificates applicable to the rest of its fleet. The rationale is that the emergency-release systems (isolated pull handles or foot pedals) in the other aircraft also require the use of either hands or feet to operate; therefore, requiring the pilot to let go of a flight control to release an external load via the manual release. With the manual release on the collective, activation is possible without requiring pilots to remove their hands or feet from primary flight controls.

This report concludes the Transportation Safety Board’s investigation into this occurrence. Consequently, the Board authorized the release of this report on 08 June 2005.

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Appendix A - Compressor Rotor Assembly

AVCO LYCOMING DIVISION
LYCOMING NO. T5311-3-OVERHAUL MANUAL



X-644-789

Compressor Rotor Assembly - Exploded View

30-3

Figure 101

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e 102

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Appendix B – Glossary

asl	above sea level
C	Celsius
CARs	Canadian Aviation Regulations
cm	centimetres
CT	compressor turbine
EGT	exhaust gas temperature
FAA	Federal Aviation Administration (U.S.)
FCU	fuel control unit
kg	kilograms
N1	refers to gas producer (compressor) rotational speed and is indicated in percentage of designed rpm
N2	refers to power turbine rotational speed and is indicated in percentage of designed rpm
NTSB	National Transportation Safety Board (U.S.)
PT	power turbine
PTG	power turbine governor
T5	turbine inlet temperature
T9	exhaust gas temperature
TSB	Transportation Safety Board of Canada
°	degrees