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AVIATION INVESTIGATION REPORT
A03O0012

LOSS OF CONTROL – COLLISION WITH TERRAIN

PROVINCE OF ONTARIO,
MINISTRY OF NATURAL RESOURCES
EUROCOPTER AS 350 B2 (HELICOPTER) C-GOGN
MEKATINA, ONTARIO
21 JANUARY 2003

Canada

Aviation Investigation Report

Loss of Control – Collision With Terrain

Province of Ontario, Ministry of Natural Resources
Eurocopter AS 350 B2 (Helicopter) C-GOGN
Mekatina, Ontario
21 January 2003

Report Number A03O0012

Summary

The Eurocopter AS 350 B2 helicopter (C-GOGN, serial number 2834) with the pilot and three passengers on board, all employees of the Ministry of Natural Resources, departed on a day, visual flight rules flight from Sault Ste. Marie, Ontario, to conduct a moose survey at a location approximately 45 nautical miles northeast of Sault Ste. Marie.

During the survey, at 1143 eastern standard time, the pilot communicated to the Ministry of Natural Resources ground-based radio operator that the aircraft experienced a hydraulic failure and that he was proceeding to a logging site at Mekatina to land the helicopter. As the helicopter approached the logging site, workers observed the aircraft proceed to the north and enter a left turn. As the helicopter proceeded back towards the logging operation in the left turn, control of the aircraft was lost and it crashed in the rising wooded terrain east of the logging site. The helicopter came to rest in an inverted position. All of the aircraft occupants were fatally injured. There was no post-crash fire.

Ce rapport est également disponible en français.

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1.0 Factual Information

1.1 History of the Flight

The helicopter departed the Ministry of Natural Resources (MNR)[1] ramp at Sault Ste. Marie Airport, Ontario, at 0910 eastern standard time[2] and landed at the slipway near the MNR Provincial Coordination Centre (PCC) where two resource technicians and one conservation officer boarded the aircraft. The helicopter departed the slipway at 0926 with an estimated time of 15 minutes to reach Block 72522, where a moose survey would commence.

At 1143, the pilot reported that the aircraft had experienced a hydraulic failure and described the logging site where he was going to land. He announced as part of his last transmission that he anticipated a rough, spot landing. The helicopter approached the logging site from the west; the logging site was a valley with a rail line running north/south. The helicopter proceeded to the south and then flew northbound over rising terrain east of the logging site (see Appendix A). Once on the east side, the helicopter levelled at approximately 50 feet above the trees, continued on a northerly heading until reaching the north end of the logging site, entered a left turn and proceeded back toward the witnesses. The helicopter remained in the left turn and in a left-banked attitude such that the witnesses, located approximately 600 feet south, could clearly see the aircraft registration markings on the underside of the aircraft. The helicopter descended into the rising terrain and came to rest inverted on a heading of 080° Magnetic. The accident occurred at 1144, at 47° 04' North latitude, 084° 04' West longitude, at an elevation of 1456 feet above sea level (asl) during hours of daylight.

Photo 1. C-GOGN wreckage

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1 See Glossary for abbreviations and acronyms.

2 All times are eastern standard time (Coordinated Universal Time minus five hours).

1.2 Injuries to Persons

	Crew	Passengers	Others	Total
Fatal	1	3	–	4
Serious	–	–	–	–
Minor/None	–	–	–	–
Total	1	3	–	4

1.3 Damage to Aircraft

The aircraft was destroyed during the impact sequence.

1.4 Personnel Information

	Captain
Pilot Licence	ATPL
Medical Expiry Date	01 May 2003
Total Flying Hours	9231
Hours on Type	920
Hours Last 90 Days	31
Hours on Type Last 90 Days	30
Hours on Duty Prior to Occurrence	4
Hours Off Duty Prior to Work Period	14

Records show that the pilot was certified and qualified for the flight in accordance with existing regulations. He had flying experience on a variety of helicopters, namely Bell Helicopter, Sikorsky and Eurocopter, and had worked for a number of commercial helicopter operators across Canada. In 2000, he joined MNR in the position of Chief Pilot – Rotary Wing.

The training that the pilot received on the helicopter included hydraulic failures in all phases of flight. The pilot passed the AS 350 B2 Pilot Proficiency Check in 2000, 2001 and 2002. He completed his most recent ground school and proficiency training on the helicopter in May 2002.

There was no indication that incapacitation or physiological factors affected the pilot's performance.

1.5 Aircraft Information

Manufacturer	Eurocopter
Type and Model	AS 350 B2
Year of Manufacture	1994
Serial Number	2834
Certificate of Airworthiness	Issued 05 May 1995
Total Airframe Time	3936
Engine Type (number of)	Turbomeca Arriel 1D1 (1)
Rotor Type (number of)	Starflex (1)
Maximum Allowable Take-off Weight	2250 kg
Recommended Fuel Type	Jet A
Fuel Type Used	Jet A

Records indicate that the aircraft was certified, equipped and maintained in accordance with existing regulations and approved procedures. The weight and centre of gravity were within the prescribed limits.

1.5.1 Aircraft Certification

The first model of the AS 350 series of helicopters to be certified in Canada was the AS 350 C model, certified on 01 June 1978. The *Direction Générale de l'Aviation Civile* (DGAC), the French civil aviation authority, withdrew the certification of the AS 350 C model in 1997. The C model is no longer certified in Canada. The AS 350 B was added to the type certificate data sheet in February 1980. In June 1988, Transport Canada (TC) Flight Test and Engineering specialists made a formal validation visit to Aérospatiale (Eurocopter) France for the AS 350 B1 model. This visit validated the AS 355 F model at the same time. Seventeen issue papers were raised and subsequently closed. The issue papers were primarily for cold-soak requirements, aircraft flight manual (AFM) changes, and airworthiness limitations. There were no issue papers related to the hydraulic system. The AS 350 B1 was certified in Canada in July 1988. The AS 350 B2 model was certified in December 1990, following an extensive internal review of technical reports. This certification did not include a validation trip. There are no indications on TC files that any specific concerns regarding the hydraulic systems were raised during any of the certification reviews.

1.5.2 Hydraulic System

1.5.2.1 General Description

The aircraft has a single hydraulic system to lighten control forces during flight and allow the aircraft to be flown at speeds where manual control loads may be excessive. The hydraulic system comprises the following:

- a power-generating section that consists of a hydraulic reservoir, a belt-driven pump, and a regulation and filtration unit;
- a power-absorbing section that consists of four servo controls (servos)[3]; and
- control and monitoring sections provided in the cockpit.

Each of the four servos includes a hydraulic actuator and a hydraulic distributor. There are three main servos: a forward servo for pitch control, and left and right servos for roll control. Each main servo is equipped with a non-return valve, an accumulator and a solenoid valve. The fourth servo is a tail-rotor servo for yaw control. The tail-rotor servo system is equipped with a non-return valve, an accumulator (fastened to an input lever in the tail-rotor control system), a solenoid valve and a check valve.

Hydraulic pressure to drive the main and tail-rotor servos is provided by a single gear-type pump, belt-driven from the main gearbox, that produces a constant outflow of six litres per minute. The pump flow rate is designed to cover servo requirements under all circumstances, and excess flow is diverted back to the hydraulic reservoir through a regulating valve that opens when the pressure exceeds 40 bar.[4] A hydraulic low-pressure switch and the hydraulic test solenoid valve are integral with the pressure regulator. The hydraulic low-pressure switch activates when the hydraulic pressure drops below approximately 30 bar, illuminating the red hydraulic warning (HYD) light on the failure warning panel and producing a continuous tone from the warning horn. The light goes out and the horn stops when the pressure switch senses a pressure greater than approximately 30 bar. The same horn provides warning of low main-rotor speed.

A hydraulic CUTOFF switch on the collective is used in emergency situations to depressurize the accumulators by simultaneously opening the three main electro valves (dump valves), excluding the tail rotor, and to facilitate a smooth transition to manual controls. When the

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3 The AS 350 B2 helicopter may be equipped with various types of servos from different manufacturers. All of the servos installed on the accident helicopter were manufactured by Dunlop Limited.

4 A "bar" is a unit of pressure equivalent to approximately 14.5 pounds per square inch.

accumulators are exhausted, the control forces become significantly higher, though not unmanageable as long as the aircraft is operated in accordance with approved procedures. Selecting the CUTOFF switch will also cancel the warning horn.

A hydraulic test toggle switch labelled "HYD TEST," located on the Geneva panel,[5] allows the main-rotor and tail-rotor servo accumulators to be tested. Placing the switch in the "Test" position causes the hydraulic test solenoid[6] and the tail-rotor servo solenoid valve to open. This causes the hydraulic pressure to drop, resulting in illumination of the hydraulic warning light and activation of the warning horn. The accumulators are tested during the pre-flight check by selecting the HYD TEST switch to "Test" and moving the cyclic stick to verify that the accumulators are providing assistance.

It is not normal practice to operate the HYD TEST switch in flight; the AS 350 B2 AFM cautions against this, as operation of the switch depressurizes the accumulator in the tail-rotor (yaw compensator) servo, resulting in high yaw pedal forces. However, if a tail-rotor control failure is experienced during flight, the AFM instructs the pilot to select the switch to the "Test" position, wait five seconds, then select the switch to the normal position. The HYD TEST switch has a distinctly shaped lever and incorporates a pull-to-unlock operation, which distinguishes it from the switches that are located on either side of it.

1.5.2.2 Hydraulic System Failure

Due to the possibility of hydraulic system failure, the aircraft was shown during certification to have adequate handling qualities when in the reversionary manual control mode, albeit with significantly higher control forces. However, at high speed, the loads are considered excessive, and a safety unit (comprising an accumulator, a non-return valve and a solenoid valve) was installed on each hydraulic servo. The accumulator charge allows the pilot time to safely reduce speed to where the manual control forces are more manageable; that is, below 60 knots. During training and pre-flight testing of the hydraulic system, MNR pilots have experienced asymmetrical depletion of the hydraulic accumulators after selecting the HYD TEST switch to "Test." Depending on the amount of control input, the typical time for the accumulators to bleed off is 20 to 30 seconds.

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[5] The Geneva panel was installed to replace the original avionics switch console.

[6] Eurocopter documentation also refers to this as the regulator solenoid.

The AFM outlines two different types of hydraulic system failures. The emergency procedures to be followed in both cases are described below:

a. In the event of a main servo control valve seizure in cruising flight, the pilot will experience stiff forces on the collective and cyclic. The emergency procedure is as follows:

- Actuate the (hydraulic) CUTOFF switch, situated on the collective pitch control lever, to cut off hydraulic pressure. Load feedback will be felt immediately; load feedback may be heavy if the helicopter is flying at high speed:
    - collective pitch: 20 kg pitch increase load;
    - cyclic: 7 to 4 kg left-hand cyclic load;
    - cyclic: 2 to 4 kg forward cyclic load;
    - yaw pedals: practically no load in cruising flight.
- Reduce speed to 60 knots and proceed as in the case of illumination of the HYD light.

b. In the event of a servo-control system failure, the HYD light illuminates. The pilot's actions for "In Flight" are as follows:

- calmly reduce collective pitch and adjust the airspeed to between 40 and 60 knots in level flight;
- cut off the hydraulic pressure, using the collective lever pushbutton.[7] Control loads are felt on the collective pitch increase, on forward and left-hand cyclic;
- if necessary, increase indicated airspeed, but the control load feedback will also increase;
- make a flat approach over a clear landing area and land with slight forward speed;
- shut down the engine, holding the collective pitch lever on the low pitch stop.

In case of a hydraulic failure, the main servo non-return valves are closed by accumulator pressure (accumulator flow is only used by the servo). The main servo solenoid valves are controlled by the CUTOFF switch on the collective lever. The pilot selects the CUTOFF switch to the cut-off position, activating the three main servo solenoid valves. This opens the servo's pressure inlet to the return line, allowing simultaneous depressurization of the accumulators.

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[7] This is the hydraulic CUTOFF switch, a covered/guarded switch and not a pushbutton.

This is designed to dump the hydraulic system pressure to zero, and also to ensure the accumulator pressures are rapidly depleted to zero symmetrically. Both these functions are required for safe operation. Dumping system pressure to zero is required to enable the pilot to depower the flight controls due to system failure or misbehaviour. Depressurizing the accumulators symmetrically and rapidly is designed to provide consistent behaviour of the flight controls when transitioning from powered to unpowered flight controls. The tail-rotor servo non-return valve is also closed by accumulator pressure and the accumulator provides reserve pressure. Unlike the main servos, the tail-rotor servo system is designed such that it can provide an almost unlimited supply of reserve pressure. If the pressure within the tail-rotor servo system exceeds 55 bar, the check valve opens the pressure line to return and allows a partial hydraulic flow as the servo piston returns to the extend position. This prevents hydraulic locking and causes the stored pressure to be reduced.

1.6 Meteorological Information

The 1600 UTC[8] METAR (aviation routine weather report) for Sault Ste. Marie reported the wind from 080° True at 4 knots, visibility 15 statute miles, broken clouds at 5400 feet, temperature -24°C, dewpoint -29°C, and altimeter setting 30.13. There were good visual meteorological conditions at Mekatina, with clear skies, calm wind and a temperature of -30°C.

1.7 Communications

All pilot communications with Sault Ste. Marie Airport tower were normal. After picking up the three passengers and proceeding to the north to conduct the moose survey, the pilot's communications were solely with a ground-based radio operator in Sault Ste. Marie. These communications were not tape recorded; however, they were documented on a radio log by the radio operator. The pilot's last transmission was logged at 1143, in which he announced that the aircraft had experienced a hydraulic failure. He described the logging area he was flying over, gave his position as 39 nautical miles north, and communicated that a spot landing may be rough. The aircraft warning horn did not sound during this communique. There were no further communications between the pilot and the radio operator. The radio operator communicated with the PCC regarding C-GOGN's predicament, and these communications were recorded at the PCC. A review of the communications indicated that the appropriate search proceedings began right away.

1.8 Flight Recorders

1.8.1 General

The aircraft was not equipped with a flight data recorder or a cockpit voice recorder, nor was either required by regulation.

8 UTC – Coordinated Universal Time

1.8.2 Aircraft Tracking System

The helicopter was equipped with a company-monitored aircraft tracking system (ATS) that provided regular position reports every 30 seconds based on latitude and longitude coordinates obtained through the international global positioning system (GPS). Additional information, such as aircraft altitude and calculated speed, is also available from the data.

A plot of the GPS position points (e.g. No. 247) for C-GOGN is shown in Appendix A. The points are joined by straight lines, as actual aircraft manoeuvring between GPS position points is unknown. The available information indicates the following:

No. 247	11:41:11	It is likely that the hydraulic failure occurred after the helicopter passed No. 247 and before reaching No. 248. The pilot reported the hydraulic failure approximately two minutes later, at 11:43.
No. 248	11:41:41	All positions prior to No. 248 reflect the helicopter's typical movements while conducting the moose survey. The helicopter departed the survey area after passing No. 248.
No. 249	11:42:11	While en route to Mekatina, the helicopter climbed from about 1800 feet asl to 2400 feet asl at an average ground speed of 81 knots.[9]
No. 250	11:42:41	At about point No. 250, the helicopter reached a maximum altitude of 2400 feet asl. It then started to descend, and over the next 1.5 minutes, descended to approximately 1700 feet asl at point No. 253.
No. 251	11:43:11	The helicopter continued to descend while en route to Mekatina. The ground speed increased to approximately 97 knots shortly after the start of the descent.
No. 252	11:43:41	The helicopter was at this approximate position when the pilot reported the hydraulic failure and described the logging site in Mekatina, where he was planning to land.
No. 253	11:44:11	The average ground speed between point No. 252 and point No. 253 had reduced to approximately 62 knots. The helicopter may have continued to decelerate after point No. 253.

9 Actual ground speed would be higher as a result of aircraft manoeuvring between ATS points.

1.9 *Wreckage and Impact Information*

1.9.1 General

The impact area was located approximately 150 feet east of the Mekatina rail siding. The area is characterized by rising terrain with light to dense forestation and an average tree height of about 80 feet. The snow depth was two to three feet in the localized occurrence area.

The helicopter struck and cut tree tops prior to striking the ground in a steep, nose-down, inverted attitude. The nose section, windscreen and overhead roof section were completely destroyed on impact. All three main-rotor blades were extensively damaged at the time of impact, but remained attached to the rotor head. The engine (Turbomeca Arriel 1D1, serial No. 9359) was attached to the helicopter; however, the mounts were damaged. Damage to the engine was unremarkable and consisted mainly of distortion of the intake and exhaust. The fuel tank, located in a compartment behind the rear seats and under the upper deck, was completely shattered.

The snow and ground under the helicopter were saturated in jet fuel, hydraulic fluid and engine oil. The tail section of the helicopter was fractured approximately five feet aft of the attachment to the fuselage, but remained attached. The tail-rotor drive shafts were damaged. The aircraft wreckage was recovered and transported to Sault Ste. Marie Airport for further examination.

1.9.2 Flight Controls

A detailed inspection of the flight control system was conducted. There were no indications of pre-impact failure, and no discrepancies were noted that would indicate a pre-existing condition that would have prevented normal operation.

1.9.3 Hydraulic System

A visual examination of the aircraft hydraulic system showed no signs of pre-impact failure of any of the mechanical components. However, the hydraulic pump drive belt was found to have fractured at a manufacturing seam where the two ends were bonded together. The belt (part number 704A33-690-004; total time since new – 390 hours) has an in-service life of 600 hours. The drive belt is a coated fabric construction, consisting of an outer coated fabric layer, two interply layers (one rubber, one fabric) and an inner rubber coating. A failure of this belt would account for the hydraulic failure reported by the pilot.

The broken belt, a number of similar unbroken belts from other MNR helicopters, and one new belt were submitted to the TSB Engineering Laboratory for examination. It was determined that the belts that had been in service were longer than the new belt. This is not considered unusual, since normal service would slightly stretch a drive belt, reducing its tension. Microscopic examination of the belts was conducted. With the exception of the new belt, extensive cracking was observed in all the comparison samples at the same location as the failure location of the occurrence drive belt. It could not be determined if the belt had failed prior to the crash; however, the cracking of the belt was examined and the belt was assessed as being close to failure prior to the crash.

Prior to the accident, as part of their normal maintenance activities, MNR maintenance personnel visually checked the belt condition on a daily basis. They also checked belt tension by feel and by attempting to turn the pulley. If the pulley turned and the belt slipped, the belt was considered to be loose. During 100-hour inspections, the belt was visually checked for damage, "feel" checked for tension, and adjusted if necessary. MNR maintenance personnel replaced the belt at the 500-hour "T" check, although the check only called for the belt tension to be checked.

All servo accumulators should have a nitrogen head pressure of approximately 15 bar. During the examination of the wreckage, the pressures in the three main-rotor servo accumulators were all found to be approximately 6 bar, and the tail-rotor servo accumulator pressure was found to be approximately 22 bar. When a hydraulic line was removed from the tail-rotor servo, hydraulic fluid sprayed out under pressure. The hydraulic components were removed from the aircraft and extensively tested, both at room temperature and while cold-soaked to -35°C. No anomalies were detected.

The hydraulic CUTOFF switch (Photo 2) on the collective was found in the forward or normal position. The switch guard was broken by impact forces and the switch housing was bent rearward. Because of the extent of the damage to the switch, the switch position prior to impact could not be determined, nor could the switch be tested for electrical continuity. The switch was disassembled and no discrepancies were noted that would indicate a pre-existing condition that may have prevented normal operation. This switch is powered through the hydraulic circuit breaker (CB).

Photo 2. Hydraulic CUTOFF switch and guard

The HYD TEST switch (Photo 3) was found in the forward or "Test" position. The pull-to-unlock design of the HYD TEST switch requires the toggle lever to be lifted up, then over the locking mechanism. Impact marks on the switch indicate that it was likely in the forward position at the time of impact. A continuity check and function testing were performed on the switch and no discrepancies were noted. This switch is powered through the hydraulic CB.

Photo 3. Hydraulic HYD TEST switch

Six hydraulic fluid samples were forwarded to the Quality Engineering Test Establishment, Department of National Defence. The test results indicated a water content ranging from 44 to 75 parts per million (ppm); the maximum allowable limit was 100 ppm. The test results did not identify any other contaminants.

1.9.4 Caution/Warning Lights/Horn and Electrical System

Stretching in the filament indicates that the light bulb in the red HYD warning light was on at the time of impact. This light illuminates when the hydraulic pressure drops below approximately 30 bar. The light bulbs in the DOORS and FUEL P caution lights exhibited stretching of their filaments and were considered to have been on as a result of the breakup of the helicopter at the time of the impact. The light bulb filaments in the remaining caution and warning lights were not stretched, and all were considered to have been off at the time of impact.

The warning horn for hydraulic pressure was function-tested, and it was determined that the horn was likely functional prior to the impact. The warning horn mute switch was found in the AFT (mute) position.

A continuity check was carried out on the aircraft's wiring system. With the exception of the hydraulic CUTOFF switch, which could not be tested due to damage, no discrepancies were noted. A continuity check was carried out by the TSB Engineering Laboratory on the Geneva panel wiring from the applicable pins in the quick-connect plugs to the Hydraulics and Rotor Warn CBs, and to the WARNING HORN and HYD TEST switches. No discrepancies were noted that would indicate a pre-existing failure condition that would have prevented normal operation.

1.9.5 Circuit Breakers

The hydraulic CB was found in the tripped position. This CB, located in the upper right-hand side of the CB panel, was the only CB in this panel that was tripped. The white trip indicator ring portion of the hydraulic CB had black streaks and an overall dirty appearance. When compared to other CBs on the same panel, none of the others exhibited a similar appearance to the white trip indicator ring. It was, therefore, assessed that the hydraulic CB was in the tripped position in flight.

To determine if the hydraulic CB could have tripped due to an electrical fault, the CB was examined and tested, and a wiring continuity check was carried out on the related wiring. No discrepancies were noted. Another option is that the CB was intentionally tripped by the pilot. This was considered highly unlikely since pulling the CB is not part of the emergency procedure, and it would be difficult for the pilot to readily identify the CB due to its location.

The hydraulic CB supplies power to both the HYD TEST switch and the hydraulic CUTOFF switch; therefore, activation of the HYD TEST switch or the hydraulic CUTOFF switch would have no effect with the hydraulic CB in the tripped position.

The rotor warning CB was found in the set position. This CB supplies power to the warning horn and the HORN caution light through the warning horn printed circuit board and the warning horn switch.

1.9.6 Summary Chart

The following chart summarizes the information from Section 1.9, highlighting the “as found” status, or position of the various switches or components, as opposed to the “anticipated” status or position if the helicopter had been configured according to flight manual requirements and expected pilot actions with a hydraulic failure.

Component	As Found	Anticipated
Hydraulic CUTOFF switch (this switch is powered through the hydraulic CB)	Forward (normal) position (actual position prior to impact could not be determined)	Aft (cutoff) position
HYD TEST switch (this switch is powered through the hydraulic CB)	Forward (Test) position	Aft position
HYD warning light	On	On
Warning horn switch	Aft (mute) position	Forward (normal) position
Hydraulic CB	Tripped	Not tripped

1.10 Survival Aspects

Witnesses ran to the crash site and immediately rendered assistance to the aircraft occupants. The aircraft came to rest in an inverted position, and the rescuers used a come-along chain to position the aircraft onto its side to gain access to the occupants. All of the occupants were wearing seat belts. The belts were cut in order to extricate the occupants from the wreckage. The Rescue Coordination Centre dispatched a C130 Hercules aircraft from Sault Ste. Marie Airport, and search and rescue technicians attended the site. The accident was not survivable due to the high-impact forces. The emergency locator transmitter activated during the crash and was turned off by a pilot who attended the site.

1.11 Organizational and Management Information

The objective of the MNR aviation program is to provide or arrange safe and efficient flying services for forest fire management, for other programs in MNR, and for other ministries and agencies in the Ontario government. As of the occurrence date, the MNR had 36 aircraft listed on the Canadian Civil Aircraft Register. Four of these aircraft are Eurocopter AS 350 B2 helicopters, including C-GOGN.

1.12 Additional Information

1.12.1 Incident Involving Another AS 350 B2 Helicopter

On 12 May 2003, an incident occurred during the pre-flight check of an AS 350 B2 helicopter at another operator (Remote Helicopters) in Alberta. The hydraulic system was shut off using the HYD TEST switch and the controls cycled to ensure that all hydraulic pressure provided by the servo accumulators was depleted. During this pre-flight check and after the accumulators were depleted, the cyclic control moved uncommanded to an extreme left position. Considerable force was required to move the cyclic. The uncommanded movement was repeatable. A servo actuator manufactured by SAMM had been isolated as the cause and was removed for further investigation. No anomalies were detected during this examination. Initiatives to try to isolate potential servo failure modes, and mitigation efforts, are described in the Safety Action section of this report.

1.12.2 TSB/TC Working Group

On 14 May 2003, the TSB convened a working group with TC personnel to examine in detail the data gathered during the investigation into the accident of C-GOGN. The working group met again at the TSB Engineering Laboratory on 28 May 2003, to witness the tear down of the hydraulic components and discuss potential safety action. The working group conducted a final meeting at the TSB Engineering Laboratory on 09 July 2003. This meeting was attended by representatives of TSB, TC, DGAC (France), Eurocopter France and Eurocopter Canada. As a direct result of the working group's activities, TC issued Airworthiness Notice (AN) D006, Edition 1, on 23 September 2003. The content of the AN is discussed in the Safety Action section of this report.

2.0 Analysis

2.1 Introduction

After experiencing a hydraulic failure, the pilot flew the helicopter for approximately three minutes while transiting to the Mekatina logging site. In the absence of an ideal landing site, he flew a low reconnaissance over the area with the intention of conducting a landing in a somewhat confined area. The helicopter crashed after departing controlled flight while manoeuvring for the landing.

This analysis will focus on the reason for the hydraulic system failure, the flight characteristics of the helicopter when hydraulics are lost, and the pilot's actions following the hydraulic failure. A hydraulic system failure in the AS 350 B2 helicopter is an emergency requiring prompt action by the pilot. The helicopter is designed to revert safely to manual controls and should be controllable to a safe landing if proper procedures are followed. However, in this case, the fact that the hydraulic CB was likely out, rendering the CUTOFF switch inoperative, would have changed the manner in which the flight control system reverted to manual controls and may have resulted in asymmetric depletion of the accumulator pressures. This may have resulted in the pilot being uncertain of the status of the hydraulic system and flight controls.

2.2 Hydraulic System Failure

The hydraulic failure was the initiating event that led to the accident. It is likely that the hydraulic pump drive belt failed in flight and precipitated the hydraulic failure. This is supported by the weakened pre-impact condition of the failed belt, the deteriorated condition of the other in-service belts that were examined, and the history of similar failures. No other explanation for a hydraulic failure was found. It is also likely that the hydraulic CB was in the tripped position in flight for undetermined reasons. The investigation of this accident has failed to reveal any other component failures in the hydraulic system that would explain why control of the aircraft was lost.

Laboratory testing of the hydraulic pump drive belt yielded some significant results. The extensive cracking in the same location in all the comparison samples (except for the new belt) indicates that a design problem may exist at that location, creating a stress/strain concentration that results in a consistent and predictable failure. The applied stresses and strains may exceed the design's strength or the service life of the belt may be too long. A review of the TC Service Difficulty Report database revealed numerous drive-belt failures that occurred during the belt in-service life of 600 hours. Since belts failed as early as 80 hours, reducing the service life of the belt is unlikely to significantly reduce belt failures.

Similarly, a visual inspection of the installed drive belt is not likely to reveal cracking or weakening at the seam. In order to have a reasonable expectation of detecting cracks with a visual inspection, the drive belt must be removed, turned inside-out, put under some tension and carefully inspected. As a result of the serviceability issues with the original belt, on 27 May 2002, Eurocopter issued Service Bulletin (SB) No. 63.00.08, offering an improved (Poly-V) belt with a significantly longer service life (1500 hours). Based on an optional SB, discussions with the manufacturer's technical representative on the unproven reliability of the new Poly-V belt, MNR's infrequency of belt failures and its self-imposed reduction in the replacement time of the belt, MNR chose not to replace its belts. Prior to this accident, MNR had only one belt failure in over 10 years of operation. Standard practice for MNR was to reduce the manufacturer's recommended belt service life and replace their hydraulic system belts at 500 hours, rather than the manufacturer's limit of 600 hours. TC subsequently issued an Airworthiness Directive (AD) on 22 April 2004 (No. CF-2004-10), mandating the new Poly-V belt modification.

It could not be determined if the pilot selected the hydraulic CUTOFF switch to CUTOFF. If he did and the hydraulic CB was tripped before he made the selection, the switch would not have functioned. In that case, the main servo solenoid valves would not be activated and the servo's pressure inlet to the return line would not be opened. The residual pressure in the main servo accumulators may not be depleted evenly, and a smooth transition to manual controls may not occur.

At some point prior to the crash, the pilot moved the HYD TEST switch to the "Test" position. This is not recommended in flight and would normally result in the loss of hydraulic pressure in the tail-rotor servo system. However, it appears that the hydraulic CB was already tripped when the HYD TEST switch was moved. This is supported by the presence of hydraulic pressure in the tail-rotor servo accumulator after the occurrence; this pressure would have provided for tail-rotor yaw control.

2.3 *Pilot's Actions*

According to his training and the AFM emergency procedures, when confronted with the hydraulics failure, the pilot would be expected to slow the helicopter to the recommended speed range (40–60 knots) and conduct a flat approach over a clear landing area, and land with slight forward speed. Since he was confronted with an abnormal situation in which emergency response actions did not result in predictable results, the pilot may have elected to fly the helicopter at higher airspeeds in order to reach the Mekatina landing site sooner. His decision on where to land may have been influenced by the depth of the snow on nearby Hion Lake, the availability of personnel at the Mekatina logging site, and the fact that the logging site was accessible by road.

As a result of not slowing the helicopter to the recommended speed, the pilot would have detected higher control forces once the accumulators on the main-rotor servos were depleted. The positions of the hydraulic HYD TEST switch and the hydraulic CUTOFF switch, as found at the occurrence site, indicated that the pilot may have attempted to dump the hydraulic pressure in flight by use of the HYD TEST switch, an inappropriate method that is not in accordance with the AFM. However, given that the pilot was confronted with an abnormal emergency situation due to the tripped hydraulic CB, it is possible that he selected the HYD TEST switch when he recognized that the CUTOFF switch did not function. There is no indication that this action further exacerbated the hydraulic emergency.

As it is likely that the hydraulic CB was tripped in flight, the hydraulic pressure from the main-rotor servos was likely depleted asymmetrically, thereby presenting the pilot with uneven cyclic loads. The experienced pilot would have been flying with a firm grip on the controls in anticipation of increased control loads associated with hydraulic pressure depletion. It is unlikely that an approximate 5 daN (deca-newton) or 11-pound sudden and short-duration increase in asymmetric cyclic load to a pilot anticipating a load increase could result in the pilot losing control of the helicopter. He may have attempted to dump the hydraulic pressure using the HYD TEST switch after realizing that the hydraulic CUTOFF switch had no effect. While manoeuvring to land at the logging site, the aircraft was seen to enter a left turn from which it did not recover. The forces encountered by the pilot during that turn at low altitude may have been too extreme to overcome, making it impossible for him to recover the aircraft to level flight.

3.0 Conclusions

3.1 Findings as to Causes and Contributing Factors

1. After experiencing a hydraulic system failure, the helicopter departed controlled flight and crashed while manoeuvring for landing. The reason for the departure from controlled flight could not be determined.

2. It is likely that the hydraulic pump drive belt failed in flight, precipitating the hydraulic failure.

3. It is likely that the hydraulic circuit breaker was in the tripped position in flight, rendering the hydraulic CUTOFF and HYD TEST switches inoperative. This would result in hydraulic pressure from the main-rotor servos being depleted asymmetrically.

3.2 Findings as to Risk

1. Laboratory examination of the failed hydraulic drive belt and other similar unbroken belts from other aircraft revealed extensive cracking in the same location in all the comparison samples. A problem may exist at that location, creating a stress/strain concentration that results in a consistent and predictable failure.

3.3 Other Findings

1. The forces encountered by the pilot during the turn at low altitude may have been too extreme to overcome, making it impossible for him to recover the aircraft to level flight.

2. The disassembly and/or examination of the four hydraulic servo controls and the components of the main-rotor controls revealed no pre-existing condition that would have prevented normal operation.

3. Hydraulic fluid test results identified a water content that was within the maximum allowable limit.

4.0 Safety Action

4.1 Action Taken

Based on the occurrence involving Remote Helicopters and this MNR accident, and referencing the initial data gathered by the TSB/Transport Canada (TC) working group, TC issued an Urgent Airworthiness Directive (AD), CF-2003-15, dated 16 May 2003. The AD, *Eurocopter (Aérospatiale) AS 350 – Loss of Hydraulic Power*, stated the following:

1. All AS350 operators inform all flight crew to perform a thorough pre-flight check and ensure that the accumulator hydraulic pressure is depleted and verified for any unusual force or movement of the controls. Investigate the cause of uncommanded movement thoroughly prior to return to service. Any irregularities need to be reported to Continuing Airworthiness Branch, Transport Canada.

2. The aircraft be landed as soon as possible after a hydraulics failure to mitigate extended utilization in manual mode.

3. Flight with hydraulics off for non-emergency situations is curtailed.

The AD was superseded by AD CF-2003-15R1, issued 01 July 2003, which stated that the pre-flight check is to be conducted prior to **EVERY** flight.

On 23 September 2003, TC issued Airworthiness Notice (AN) D006, Edition 1, the purpose of which was to update aircraft owners/operators, maintainers and pilots of AS 350 rotorcraft on the TSB investigation. Specifically, it addressed concerns expressed with the flight control characteristics of the AS 350 when the hydraulic system pressure is lost. One anomaly addressed in the AN is stated as follows:

1. Uncommanded movement when system is being depleted: Eurocopter ground test demonstrated that an uncommanded movement is possible when one lateral accumulator is depleted and the other charged. Based on this test, Transport Canada concluded that a similar result may be expected in flight.

   Mitigating Factors:

   The above uncommanded input is prevented in-flight when the pilot follows the Aircraft Flight Manual (AFM) procedure, which indicates that following a hydraulic failure, the aircraft is slowed promptly to a specified speed and the hydraulic cut-off is activated. By activating the cut-off, any unbalanced force as a result of asymmetrical residual accumulator pressure is avoided. If the hydraulic cut-off is not activated, then the sustained asymmetrical pressure

> may occur if the accumulator depletes at a different rate until the residual pressure is depleted through normal movement of the flight controls. The force identified by the Eurocopter test would be approximately 5 daN (11 pounds).

The AN states in part that TC, in cooperation with the *Direction Générale de l'Aviation Civile* (DGAC), has undertaken to continue to examine the servos that have been removed as a result of uncommanded movement to ensure that there are no hidden failure modes. Also, TC intends to conduct a review of all flight control failure modes related to the control systems and associated in-flight handling qualities in various flight regimes and environmental conditions.

On 22 October 2003, the TSB issued to TC an Aviation Safety Advisory (A030019) to address the extensive cracking deficiency on the hydraulic pump drive belt. Although the belt manufacturer has produced a modification that incorporates a Poly-V design drive belt, there are numerous helicopter operators in Canada that continue to operate their aircraft with the occurrence type hydraulic pump drive belt. On 22 April 2004, TC issued an AD (CF-2004-10) mandating the replacement of the occurrence type belt with the improved belt by 30 September 2004.

Following the accident involving C-GOGN, MNR grounded its fleet of Eurocopter AS 350 B2 helicopters. The helicopters did not go back into service until late March 2003, after the hydraulic pump drive belt modification (Poly-V belt) was completed. The new Poly-V belt has a service life of 1500 hours; however, MNR will replace these belts at 1000 hours. MNR directed its maintenance engineers to conduct a thorough inspection on the AS 350 B2 helicopter hydraulic and flight control systems. Additional flight training, focused on the hydraulic system failures and emergency procedures, was provided to all MNR pilots. MNR staff and management were provided with a question-and-answer sheet to address staff questions pertaining to the accident, and a Critical Incident Stress Management session was offered to all MNR staff.

During the investigation, TC continued to receive additional Service Difficulty Reporting reports indicating unexplained uncommanded movement. The TSB agreed that the TSB/TC working group continue, and TC has shared service difficulty data. At a joint meeting arranged by the TSB, which included TSB, TC, DGAC, Eurocopter France, Eurocopter Canada and MNR, a request for data was made to the manufacturer to specifically address the cold-weather effects on the handling qualities of the aircraft and to provide an analysis of flight control system failure modes and effects.

The response provided by Eurocopter indicated a lack of certification data concerning loss of hydraulic power and transition to manual flight in cold temperature conditions. As a result, TC requested a detailed engineering review of the flight control and hydraulic system with Eurocopter.

A meeting at Eurocopter was held during which Eurocopter presented a conservative analysis of the control forces in manual mode at very cold temperatures. This analysis indicated that possible loads could be experienced that would be beyond the strength capability of the pilot to ensure continued safe flight and landing of the rotorcraft.

On return from the engineering review, TC was informed that another Canadian operator (Canadian Helicopters) had experienced an uncommanded left input during the final phase of flight after shutting down the hydraulic system due to an apparent irregularity in the flight control forces. Control was regained upon repressurizing the hydraulic system. This event further supported the immediate need for a flight test campaign (occurrence A04O0015, involving an AS350BA, not investigated).

Eurocopter Canada arranged for a Canadian aircraft to be instrumented by Eurocopter France for extreme cold-weather testing at Inuvik, Northwest Territories. During the preparation for this test, the operator identified additional concerns regarding evidence of water ingress into the hydraulic system and external contamination. The scope of the testing was expanded to not only include flight control loads in powered and manual flight while monitoring temperatures and pressures, but also to investigate water ingestions and external contamination.

The results of this campaign revealed:

- Manual flight control loads at these temperatures are acceptable but marginal in longitudinal direction. This datum confirmed that the pilot requires forward speed to ensure positive control margins.
- Higher-than-expected residual hydraulic pressure with the system in bypass. These pressures were high enough to defeat the non-return check valve, allowing hydraulic power to the servos. This is of concern if a control valve were to jam in a position resulting in control forces beyond what a pilot would be able to control.
- At temperatures below -15°C, the main-rotor servos are at the freezing point.
- External ice may form but will not prevent control movement.
- Significant amount of water was added to the hydraulic system with no immediate effects identified.

The results of these tests were provided to the DGAC to take necessary corrective action as State of Design. The DGAC took the following corrective actions, which are mandatory in Canada:

- Rotorcraft Flight Manual changes to improve normal and emergency procedures, improved hydraulic system description and enhanced hydraulic system failure training procedures. These are mandated by AD CF-2003-15R2.

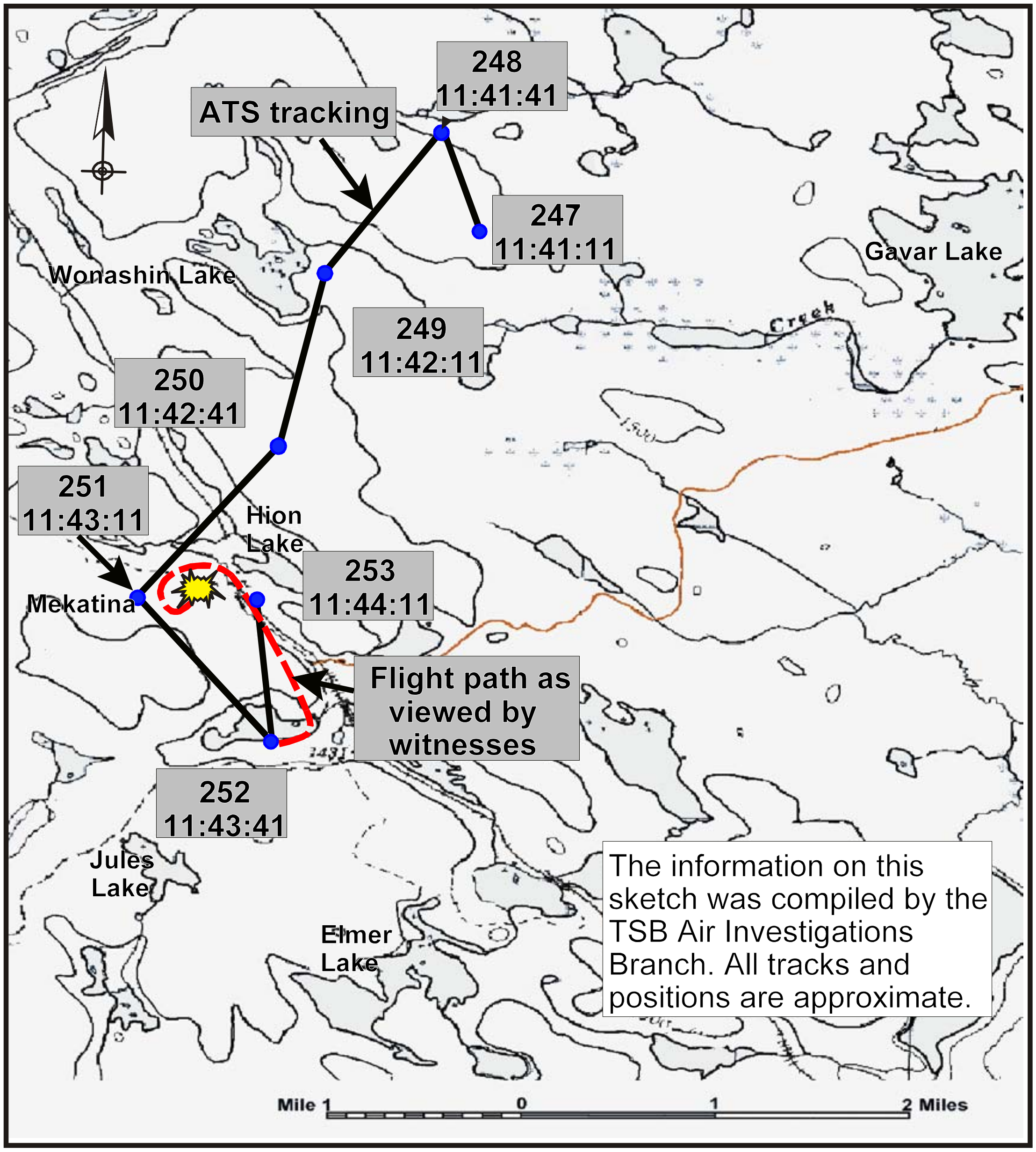
- Require modification to the hydraulic bypass system to reduce residual pressure to an acceptable level. The DGAC issued AD F-2004-089 dated 23 June 2004. This was superseded by TC AD CF-2004-15 to require installation prior to the next cold weather season.

- Issued AD F-2004-055 on 28 April 2004, to require hydraulic fluid replacement when exposed to temperatures below -15°C to ensure water ingested into the system is removed to an acceptable level.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 26 January 2005.

*Visit the Transportation Safety Board's Web site (**www.tsb.gc.ca**) for information about the Transportation Safety Board and its products and services. There you will also find links to other safety organizations and related sites.*

Appendix A – C-GOGN ATS Tracking



Appendix B – List of Supporting Reports

The following TSB Engineering Laboratory reports were completed:

LP 011/2003 – GPS and Laptop Data Recovery
LP 025/2003 – Hydraulic Fluid
LP 026/2003 – Examination of Hydraulic Pump Drive Belt
LP 031/2003 – Eurocopter Systems Examination

These reports are available from the Transportation Safety Board of Canada upon request.

Appendix C – Glossary

AD	Airworthiness Directive
AFM	aircraft flight manual
AN	Airworthiness Notice
asl	above sea level
ATPL	airline transport pilot licence
ATS	aircraft tracking system
CB	circuit breaker
daN	deca-newton
DGAC	*Direction Générale de l'Aviation Civile*
GPS	global positioning system
kg	kilogram(s)
METAR	aviation routine weather report
MNR	Ministry of Natural Resources
PCC	Provincial Coordination Centre
ppm	parts per million
SB	Service Bulletin
TC	Transport Canada
TSB	Transportation Safety Board of Canada
UTC	Coordinated Universal Time
°	degree(s)
°C	degree(s) Celsius
'	minute(s)