Transportation Safety Board of Canada
Bureau de la sécurité des transports du Canada

AVIATION INVESTIGATION REPORT
A03P0194

COLLISION WITH TERRAIN

AIR SPRAY (1967) LTD.
LOCKHEED L-188 ELECTRA C-GFQA
CRANBROOK, BRITISH COLUMBIA 2.5 nm SOUTH
16 JULY 2003

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.

Aviation Investigation Report

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Summary

At about 1210 mountain standard time (MST), Tanker 86, a four-engine Lockheed L-188 Electra (C-GFQA, serial number 188A-1040) took off from Runway 16 at the Cranbrook Airport, British Columbia. Two pilots were on board to conduct a fire-management mission on a small ground fire (designated N10156) two nautical miles southwest of the township of Cranbrook. Seven minutes earlier, the partner "bird dog" aircraft, a Turbo Commander, also departed Cranbrook to assess the appropriate aircraft flight path profiles and to establish the most suitable fire-retardant delivery program for the ground fire.

Following the flight path demonstrations by the bird dog aircraft, Tanker 86 proceeded to carry out the retardant drop on the fire. After delivering the specified retardant load, Tanker 86 was seen to turn right initially then entered a turn to the left. At 1221 MST, the Electra struck the terrain on the side of a steep ridge at about 3900 feet above sea level. The aircraft exploded on impact and the two pilots were fatally injured. An intense post-crash fire consumed much of the wreckage and started a forest fire at the crash site and the surrounding area. The on-board emergency locator transmitter was damaged by the impact forces and did not activate.

Ce rapport est également disponible en français.

Other Factual Information

The Bird Dog Aircraft

On board the Turbo Commander bird dog were its pilot and two air attack officers (AAOs) from the British Columbia Forest Service (BCFS). Part of the AAO function is to assess ground fire characteristics and devise the most effective and safe flight paths, retardant dispersal patterns, and delivery profiles. The bird dog pilot is an integral partner in this process and provides operational flight performance input to help the AAO plan and coordinate the attack on a fire scene. The pilot is involved in planning and checking the aircraft routes over the drop zones, especially in leading the tankers into their retardant drop flight paths. Once the planned flight route is decided upon, the bird dog pilot flies the aircraft on that profile in a demonstration run for the tanker pilots. During the demonstration flight, the AAO provides a real-time commentary to the tanker pilots, identifying the routes in and out, landmarks, salient points, and hazards along the flight path.

History of the Flight

In the minutes leading up to the accident, the bird dog aircraft flew the approximate route while the AAOs determined that two separate retardant drops, forming a "V", would be required, and that the altitude over the drop zone would be 3700 feet above sea level (asl). Since a straight-out exit from the first run over the drop zone (heading of about 155° magnetic[1]) would take the Electra into rising terrain, the AAOs decided that the safest exit route after the drop was a 35-degree right turn into a wide valley, which was substantially flatter, and toward Moyie Lake. High-tension electrical power lines crossed beneath the exit route from the fire site, and although the lines were lower than the proposed flight path, the AAOs included them in their summary as a caution.

The bird dog then flew the proposed retardant drop flight profile, the first of two such runs while the Electra circled overhead at 5000 feet asl and watched the demonstration. For operational efficiency, after exiting to the right and passing the power lines, the bird dog turned left to return to commence the second run. The Electra pilots accepted this first run, adding that they would turn right, down the valley (toward Moyie Lake) as described in the AAO commentary.

Photo 1. Tanker 86 delivers retardant to target fire at 1220 mountain standard time

1 All headings in this report are expressed in degrees magnetic.

The bird dog then carried out the second demonstration run, which the Electra pilots also accepted. On this run, the bird dog flew the same right-turn exit path before turning left to join up with the Electra to fly in the standard "seven o'clock" formation position so as to observe the retardant drop. As a result of the second bird dog run, the Electra pilots again confirmed that, after the retardant drop, they would turn right and exit down the valley. After observing the two demonstration circuits flown by the bird dog aircraft, the pilots on Tanker 86 left their orbit and proceeded to carry out the first retardant drop on the target fire.

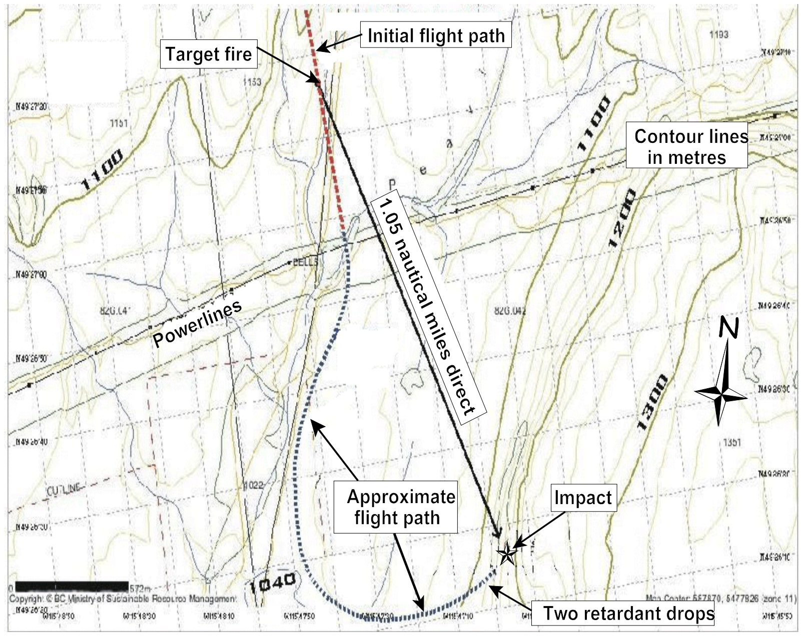

Figure 1. Final flight path of Lockheed L-188 Electra C-GFQA

The bird dog joined up with Tanker 86 and followed on the left, rear quarter as it flew over the drop site. After the Electra released the specified retardant load, at 1220 mountain standard time (MST),[2] the bird dog entered a right-hand turn to circle the fire zone to allow the AAOs on the right side of the aircraft to assess the drop. At the same time, and as the Electra passed over the power lines, its flying pilot transmitted that they were in the right turn. The tanker was seen to turn right initially, then turn left. About 50 seconds later, Tanker 86 was seen in an extreme, left-bank angle immediately before it struck the ridge and exploded (see Figure 1).

While the tanker was flying away from the drop site, the bird dog was turning right using approximately 40 degrees of bank. After the bird dog had turned about 300 degrees, the AAO saw the Electra in the left bank for about three seconds before it struck the terrain and exploded. In those last seconds before impact, there were two separate retardant drops into the trees. No further communication was received from the Electra after the pilot announced the right turn passing the power lines. Ground witnesses reported hearing the noise level of the engines on the Electra significantly increase seconds before the aircraft struck the terrain.

Based on the 300-degree right turn by the bird dog and its associated rate of turn, investigators calculated that the Electra would have flown for about one minute after the drop before colliding with the terrain. This flight time is corroborated by air and ground witnesses. Photographic records of the first retardant drop show that the Electra had been on the planned flight profile (3700 feet asl).

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2 All times are MST (Coordinated Universal Time [UTC] minus seven hours), unless otherwise indicated.

Although not arranged in similar detail as the first retardant drop, it was understood by the AAOs and pilots that, after the first drop, the Electra would climb back to 4500 feet and await the demonstration run for the second retardant drop, that is, the other half of the "V." Considering the surrounding terrain and the next task, the most practicable and reasonable flight path for the Electra after completing the exit from the first run would have been a climbing left turn to 4500 feet.

Wreckage Description

The Electra was destroyed by severe impact forces and a fierce, post-impact fire. The disintegration of the aircraft was extensive and about 35 per cent of the airframe was consumed by fire. The powerplants were recovered and examined separately. All the remaining wreckage was recovered from the accident site and examined to the extent possible. No pre-existing defects or anomalies were found. All flight control surfaces were accounted for and there was no indication of pre-impact failure or in-flight separation. Similarly, the flight control linkages and hydraulic systems showed no signs of premature failure or malfunction; however, they were heavily damaged and, as a result, investigators were unable to examine them completely.

Accident Site Description

Tree damage and ground impact scars show that the Electra was in a left angle of bank of about 70° and nose-low when it first struck the trees at the edge of the accident site (see Photo 2). The terrain at the site is a steep and rugged talus, generally on a 45-degree slope from the ridgeline above, and thinly populated with tall evergreen trees. This part of the ridge juts out briefly from the smooth contour of the ridgeline and forms a "bulge."

Photo 2. Profile of C-GFQA at impact

The surrounding area is more densely tree-covered and tends to conceal the bulge and rock outcrop that the aircraft struck. The terrain adjacent to the initial flight path slowly rises to the east and includes the accident site ridge, with the exit route down the valley toward the south and Moyie Lake (see Photo 3). This area provided ample manoeuvring room over relatively flat terrain. The ridge that the aircraft struck blended into the rising terrain and was not obviously separate from its surroundings.

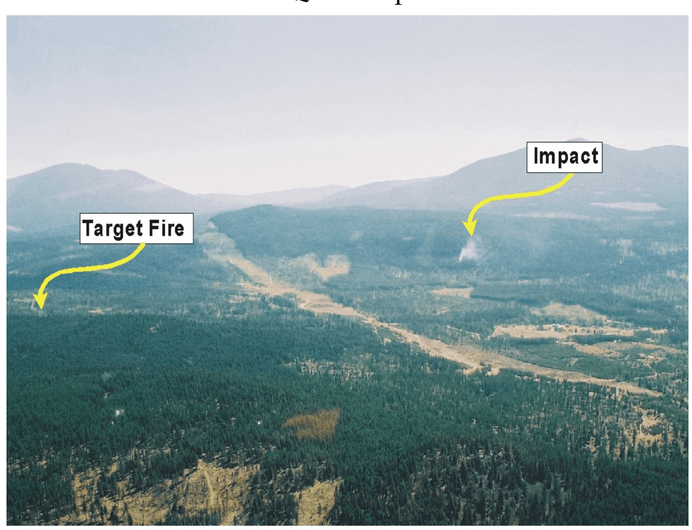

Photo 3. View of valley to the southeast

Flight path recreation performed by both fixed- and rotary-wing aircraft at the same time of day and lighting conditions as the accident revealed that the ridgeline and the land mass that jutted out from it were particularly difficult to discern until about 0.5 nm away, even with prior knowledge. As well, the sun was overhead at the time of the accident and there was a lack of shadow relief, compounding the visual acuity problem.

The Canadian Forces Directorate of Flight Safety (DFS) conducted an investigation into the fatal crash of a military Search and Rescue DHC-6 Twin Otter (number 13807) at Cox Hill, Alberta, that occurred at 1452 mountain daylight time on 14 June 1986. It was concluded that the principal contributing factor in this accident was pilot visual illusion brought about by the low flight path, the terrain features, and the high position of the sun at the time of the accident. Research carried out by the United States Air Force Safety Center found that pilot orientation—specifically altitude perception and obstacle rate of closure—was significantly affected by those same factors, leading to visual illusion and loss of situational awareness.

Furthermore, many pilots recognize that vision limitations resulting from cockpit design and layout characteristics can reduce a pilot's opportunity to detect obstacles in the flight path ahead in a timely manner.

Pilots

Each pilot was trained and licensed appropriately for the Lockheed L-188 Electra and the fire-retardant delivery mission. They were both highly experienced and qualified tanker pilots, and each had worked for the operator in the fire-management area for several years. A review of their flight and duty times for the period leading up to the accident revealed no deviation from Transport Canada (TC) regulations respecting flight and duty time limits, and neither had been recently engaged in arduous operational activities. The pilots' medical records were unremarkable; there was no information of incapacitation or of any pre-existing medical condition that could have contributed to the circumstances surrounding this accident.

Weather

There were no formal weather observations for the area of the accident, but witnesses reported that the sky was clear and the wind was approximately 15 knots from the southeast. A review of photographs taken immediately after the accident supports this assessment and shows no indication of turbulence or significant down-flowing wind in the general area of the accident site. The weather is not considered to have been a contributory factor in this accident.

Communication

The Turbo Commander and the Electra had both been in normal communication with the Cranbrook Flight Service Station (FSS) on departure from the airport and had changed to an operational radio frequency (122.625 MHz) once in the area of the target fire. For the period of recorded communications with the FSS leading up to the accident, no indication of any aircraft malfunction was given, nor was any message of urgency from the Electra pilots heard. Radio communications between the bird dog and the Electra were clear and normal, consisting of conventional and appropriate terminology, with no indication of unexpected circumstances or anomalies. No communication was received from the Electra pilots after they turned over the power lines.

The on-board emergency locator transmitter (ELT) unit (Dorne and Margolin–DM ELT 6.1) was damaged at impact and rendered inoperative. Examination by the TSB Engineering Laboratory in Ottawa, Ontario, shows that the unit was functional at impact and would have been capable of transmitting a signal; however, the severe impact forces exceeded the ELT design criteria.

Retardant Tank System

Both Air Spray L-188 Electras (C-FVFH and C-GFQA) were permanently fitted with a large retardant belly tank, the Air Spray constant variable-flow tank system, specifically designed and installed by Aero Union of Chico, California, U.S., for in-flight release of fire retardant. The tank held a maximum of 2500 imperial gallons (11 365 litres) of water or retardant mixture. The system was approved by the U.S. Federal Aviation Administration (FAA) and TC.

The belly tank system in C-GFQA incorporates a computer-controlled, variable-release drop mechanism that allows the pilots to release a selected amount of retardant. The pilots can select, on the selector panel in the cockpit, to release the whole load or a fraction of it. The retardant is then released when a thumb-button on the left control wheel is pressed. Only the left control wheel has the release button.

In the centre pedestal between the two pilots, there is a guarded, emergency dump switch that releases the total content of the belly tank at once. To function in both normal and emergency modes, the belly tank system requires electrical power from the aircraft electrical system and hydraulic pressure from the aircraft hydraulic flight control systems. The opening and closing of the belly tank doors for retardant release occurs in a time frame of between one to three seconds, depending on the selection made in the cockpit. In this accident, the pilots had selected 1/6 of a load—about 420 imperial gallons—that would have weighed about 4450 pounds.[3]

Flight Data Recorders

Flight recorders were not required by regulation to be installed in the aircraft. No flight data recorder was installed; however, a Rockwell-Collins analog cockpit voice recorder (CVR) unit was recovered from the wreckage and sent to the TSB Engineering Laboratory for examination and retrieval of data. The CVR unit had survived the impact and fire with only moderate damage. The audiotape was intact and the recorded analog communication information was readable but contained information recorded during winter operations in a previous year. Since there was no requirement for a CVR in this aircraft, the CVR had not been maintained and was not turned on for flight operations. It could not be determined if electrical power was still available to the CVR at the time of the accident.

The Electra was equipped with global positioning system (GPS) telemetry tracking systems[4] that recorded selected flight navigation data, which enabled accident investigators to reconstruct the flight path of the aircraft from take-off to the planned retardant drop. The GPS flight data are captured at 30-second intervals and transmitted from the aircraft in data packets every two

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3 Retardant specific gravity was 10.6 pounds/gallon (imperial)

4 Latitude Mobile Controller

minutes, provided line-of-sight satellite communication is available.[5] The last received and recorded position of the aircraft occurred just before the planned retardant drop at the subject fire. It is likely that the aircraft attitude in the seconds before impact inhibited the effective transmission of the last data packet. The Latitude Mobile Controller (LMC) was destroyed by impact forces and the post-crash fire and, as a result, the last recorded flight data elements were lost and no accurate electronic information is available regarding the altitude, speed, or track of the Electra for about two minutes before impact.

Aircraft Weight and Balance

The design gross weight for this L-188 model Electra is 113 000 pounds. The maximum certificated take-off weight for C-GFQA as a tanker is 105 000 pounds with a centre of gravity (CG) range of 571.2 to 591.4 inches from the datum, depending on the actual weight. Using the most recent weight and balance records and the loading data from Cranbrook, investigators determined that the aircraft was about 103 000 pounds at take-off with the CG at 580 inches from the datum, and within the certificated weight and balance limits. Because of fuel burn and retardant release, the aircraft would have weighed about 96 950 pounds during the left turn leading to the accident, and about 87 950 pounds at impact. At both weights, the CG was within limits. Accordingly, incorrect aircraft weight and balance is not a factor in this accident.

Aircraft Performance

In part, the Air Spray standard operating procedures (SOP) for the Electra when dropping fire retardant required an airspeed of 135 knots with the flaps extended to 100 per cent.[6] The photographic record of the fire drop shows the flaps extended to a position consistent with 100 per cent. After the load has been released, the SOP required the pilot to apply *maximum continuous* engine power (see adjacent table), retract the flaps to 78 per cent, and accelerate to 150 knots. At the same time, the pilot manoeuvres the aircraft to follow the planned exit route.

Engine Condition	Percentage of MRT
Take-off	100
Maximum Continuous	96.9
Maximum Climb	94
Maximum Cruise	90

MRT = Maximum Rated Thrust

501-D13 engine power settings

The flaps on this aircraft are moved by four extensible jack screws that are hydraulically powered and cable-controlled. By design, the jack screws stop moving when hydraulic pressure to them is interrupted, thus capturing the last position. The length of the jack screw is directly proportional to the amount of extended wing flap, and measuring the jack screw length provides the percentage of flap, accurate to the order of ±5 per cent flap extension.

The four jack screws were recovered at the accident site and measured; the figures varied from 29.25 to 31.25 inches. Using empirical data from the sister Electra (C-FVFH) as a baseline, these measured lengths are consistent with a flap extension of approximately 73 per cent. Considering that the four jacks were closely similar in length, and that minor mechanical differences probably existed between the two Electras' flap systems, it is likely that the flaps were near the

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5 If satellites are not available, GPS data are stored and sent at the next opportunity.

6 100 per cent flap extension equates to 40° wing flap angle, and 78 per cent equates to 18°.

required position of 78 per cent when C-GFQA struck the terrain. It could not be determined when the flaps were retracted from the 100 per cent position, but it is likely that the pilot retracted them in accordance with the Air Spray SOP, that is, immediately following the retardant drop.

TSB investigators and Lockheed Martin Aeronautics Company specialists carried out several calculations to examine the most likely in-flight performance of C-GFQA in the conditions and aircraft configuration leading up to the accident.[7] In summary, the calculations showed that, immediately after the drop, C-GFQA could have climbed straight out at approximately 1500 feet per minute (fpm) with *maximum continuous* power at 150 knots and 78 per cent flap, and at about 1000 fpm with a 45° angle of bank (see the adjacent rate of climb table). Calculations further show that the application of *take-off* power would have increased these rates by about 200 fpm. No calculations were made with greater bank angles, but it can be reasonably predicted that the rates of climb would have been reduced remarkably as the angle of bank increased.

Rate of climb (fpm)			
Airspeed (knots)	***Angle of bank***		
	0	30	45
135	1430	1240	1010
150	1510	1310	1060

Further calculations were made to examine the effect on climb performance as a result of dumping all or part of the retardant load. It was determined that jettisoning two 1/6 loads of retardant (9000 pounds) would have improved the rates of climb by about 270 fpm and the stall speed margins by about five knots. Had the pilots used the emergency dump, thereby jettisoning the entire load of remaining retardant (22 500 pounds), the rate of climb increase would have been approximately 800 fpm, and the stall speed margin would have improved by 13 knots.

Analysis of aircraft performance calculations show that, at 78 per cent flap and *maximum continuous* power, the rate of climb is positive for any airspeed and bank angle combination between the stall speed and the flap limit speed of 190 knots.[8] However, in level flight with bank angles greater than 60 degrees, the stall speed rapidly exceeds 140 knots. Furthermore, the resulting load factor for such bank angles would make it difficult for the flying pilot to hold the aircraft in a level turn for any length of time. An angle of bank of 70°, for example, produces a load factor of 2.9 g.[9] Once C-GFQA rolled past a 60° angle of bank with the flaps extended to 78 per cent, the aircraft would have exceeded the limits of the certificated operating envelope, and in all likelihood would have stalled.

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7 It should be kept in mind that these theoretical performance figures presuppose specification performance engines and propellers, without allowance for airframe age or in-flight operational factors, such as low-level manoeuvring. In practice, the climb performance of the aircraft engaged in fire-management activities is noticeably less than theoretical.

8 FAA Type Certificate Data Sheet No. 4A22(I), Model L188A (25 October 2001)

9 The normal measure of "g" load on an object is the "load factor" or "g", which is the ratio of the force experienced under acceleration to the force that would exist if the object were at rest on the surface of the earth.

Aircraft performance calculations were carried out to determine the radius of turn for varying airspeeds and bank angles, and the results for an airspeed of 140 knots are shown in the following table. The ratio between indicated air speed (V) and stall speed (V_{stall})—*stall speed ratio*—is included for reference.

Angle of bank (degrees)	10	20	30	40	50	60
Radius of turn (feet)	10 985	5322	3355	2308	1625	1118
Stall speed ratio (V/V_{stall})	1.40	1.36	1.31	1.24	1.13	0.99

The distance from the power lines to the accident site is about 0.75 nm (4550 feet), and after the right-hand exit turn, the lateral span available across the valley to the ridgeline is about 0.65 nm (4000 feet). (See approximate flight path in Figure 1.)

Aircraft Maintenance

A review of the available aircraft technical logs indicates that C-GFQA was certificated and maintained in accordance with TC regulations and required standards. The aircraft had been originally manufactured as the passenger-carrying commercial Electra model by the Lockheed Martin Aircraft Corporation (formerly Lockheed Aircraft Corporation) in 1959. At the time of the accident, the aircraft had accumulated about 38 775 hours' total flight time. In comparison to other aircraft in the global L-188 fleet, this total flight time is quite low.

Engines

The Lockheed L-188 Electra was equipped with four Rolls Royce Corporation (formerly Allison) 501-D13 model turboprop engines. All the engines and associated propeller hubs and blades were taken to the TSB regional wreckage examination facility in Richmond, British Columbia, for inspection and examination. As well, all four propeller hub assemblies and blades were taken to the approved overhaul facility in Seattle, Washington, U.S., for detailed examination, disassembly, and analysis under the direct supervision of TSB investigators.

TSB investigators and specialists from the airframe and propeller manufacturers visually assessed the external appearance, damage patterns and characteristics of the hubs and propellers. It was concluded that all four engines were delivering high power at impact for the conditions and aircraft configuration at that time.

Forensic examinations of the hub mechanisms were carried out to determine the overall functionality of each hub and the angle of each blade at impact. In summary, the examinations of the engines and propellers revealed no pre-existing defect or anomaly that would have contributed to this accident, and all the components were within specification limits.

The examination and analyses of the propeller blades, hubs, and internal spline gears revealed damage characteristic of sudden impact at high rpm, and that the angle of the blades at impact varied in the range of +38° to +46°. By design, at all power settings in flight, the propeller on this engine installation turns at a constant speed, through a reduction gearbox, equivalent to 13 820 ± 140 engine rpm.

Given the in-flight conditions at the time of the accident, the estimated speed of the aircraft, and the anticipated engine power settings during the last seconds of flight, the propeller blade angle would have been in the order of 42°. This theoretical value could vary between engine and propeller combinations, and would be influenced by component wear and dynamic tolerances in the mechanical linkages and mechanisms. Accordingly, the range of blade angles that was determined by examination is consistent with normal and expected values on engines developing significant power at impact. Moreover, the fact that the blade angles were alike demonstrates that the engines were delivering similar high levels of power.

Several cockpit instruments and warning panels were recovered from the accident site and sent to the TSB Engineering Laboratory for examination and analysis. In summary, the instruments bore witness marks caused by multiple impacts. The witness marks were consistent with the four engines operating at high power (2600 to 2800 HP) and rpm (12 000 to 12 800) at impact. From this analysis, it can be concluded that any loss of engine power was not a contributory factor in this accident. As well, the examination of one airspeed indicator revealed impact witness marks at the 120-knot position, which is consistent with the estimated speed at impact.

Light bulbs from the warning panels were examined to determine whether or not they were illuminated at impact. No reliable analysis was possible.

Analysis

The aircraft wreckage was examined to the extent possible, given the massive destruction and loss by fire. No evidence of system malfunction or pre-existing defect was found. All flight control surfaces were accounted for at the accident site and no sign of in-flight detachment or malfunction was identified. The sightings of the aircraft seconds before impact confirm that it was intact, without sign of fire, with all engines operating, and with the hydraulic and electrical systems functioning. Further, the fact that the pilot flying released two loads before impact signifies that he was conscious and aware of the situation they were in at that time.

Since there was no communication or witness accounts to the contrary, nor was the emergency dump system employed, it would be reasonable to conclude that, in this relatively simple and benign flight task, the pilots had not experienced an aircraft flight control malfunction. Additionally, the low rate of climb demonstrated by the aircraft—in the absence of mechanical reason—suggests that the pilots were not aware of their proximity to the rising terrain. A discussion of these two issues follows.

Given the flight time and the distance to the impact point, the permutations of the radius of turn for various airspeeds show that the Electra would have described an arc over the ground dictated by two variables—airspeed and bank angle—with the wind as a constant. Accordingly, the most likely airspeed-bank combinations range from 135 to 150 knots and 40 to 45 degrees, neither of which is unreasonable for this type of operation. Such a flight path is consistent with purposely controlled flight. Values outside these finite ranges were found to produce great divergence from the last minute of flight path and were discounted. The exit route down the valley toward Moyie Lake was always available to the pilots in the event of a mechanical malfunction that required manoeuvring room over flat terrain. Accordingly, since the aircraft did not deviate from its arcing path to the left, it is unlikely that the pilots were dealing with a situation preventing climb performance or with a flight control malfunction. Furthermore, the fact that the aircraft was seen flying in a conventional attitude until shortly before impact suggests that the pilots were in control of the aircraft.

Examinations of the engines and propellers consistently show that the engines were delivering similar and high power at impact. The reasonable conclusion is, therefore, that the engines were capable of delivering rated power before the impact. In concert with the airspeed and angle of bank calculations, the results of the rate of climb assessments reveal that the Electra could have attained climb rates in the order of 1000 fpm at any stage during the left turn. Accordingly, with consideration of the known flight path and altitude profile, no mechanical reason, aerodynamic effect, or performance factor was found that would have prevented the aircraft from attaining sufficient altitude to avoid the terrain.

Without the likelihood of either aircraft mechanical defect or flight performance inadequacy, the explanation as to why the aircraft did not climb to avoid the terrain becomes one of human performance. With an aircraft capable of controlled, climbing flight, it would be reasonable to conclude that the pilots flew the vertical profile after the drop on the target fire and gently climbed from 3700 feet to at least 3900 feet. It could not be determined if the aircraft climbed more than the observed 200 feet difference, only to lose it again. It is also possible that, after initiating a satisfactory rate of climb for the seemingly benign task to climb to 4500 feet, the pilots became distracted in the cockpit and unintentionally allowed the climb to deteriorate. Because of the lack of direct knowledge of the cockpit circumstances leading to the accident, the reason for the pilots not climbing their aircraft cannot be identified with any certainty. Nonetheless, several factors exist that collectively lead to a possible explanation.

Documented research[10] shows that mountainous terrain in daylight, especially at midday with little shadow outline, lacks effective visual definition and is particularly difficult for pilots to assess for slope, proximity, and rate of closure. In such conditions, visual illusion and depth misperception is quite likely.

In this accident, the characteristics of the terrain were similarly difficult to assess, and it is most likely that the Electra pilots were deceived by the apparent gently sloping nature of the surrounding terrain and did not detect the ridgeline that crossed their flight path. To them, the ridgeline and the protruding land mass would have been difficult to discern clearly until the aircraft was so close that timely and effective evasive action was impossible. Compounding their difficulty in detecting the obstacles ahead of them were the limitations to unimpeded vision resulting from the left bank in the turn toward the rising terrain, which reduced their perspective and field of vision, and the physical dimensions of the cockpit windshields. It can be said with some degree of certainty that the pilots were unaware that they were on a collision path with the terrain until the very last seconds before impact, otherwise they would have altered course and flown the simple, low-level emergency route down the valley toward Moyie Lake.

Low-level, fire-management flight operations continually challenge the situational awareness skills of pilots and require assiduous attention to the terrain, aircraft performance, and effective crew resource management. Vision limitations resulting from cockpit design and layout characteristics can further reduce a pilot's opportunity to detect obstacles in the flight path ahead.

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[10] Canadian Forces Directorate of Flight Safety and United States Air Force Safety Center

Findings as to Causes and Contributing Factors

1. For undetermined reasons, the Electra did not climb sufficiently to avoid striking the rising terrain.

2. Given the flight path and the rate of climb chosen, a collision with the terrain was unavoidable.

3. The characteristics of the terrain were deceptive, making it difficult for the pilots to perceive their proximity and rate of closure to the rising ground in sufficient time to avoid it.

Other Findings

1. Performance calculations show that the Electra—in the absence of limiting mechanical malfunction—could have climbed at a rate that would have allowed the aircraft to avoid the terrain.

2. Although a functional cockpit voice recorder was installed in the aircraft, it was not required by regulation and it was not used; as a result, vital clues that could have shed light on the circumstances of this accident were not available.

3. The emergency locator transmitter could not transmit a signal as a result of severe impact forces that exceeded the design criteria.

Safety Action Taken

British Columbia Forest Service

The Aviation Management Division of British Columbia Forest Service (BCFS) participated in the TSB investigation and conducted an internal examination of the circumstances to identify and correct any BCFS-related flight safety factors. Its report found that the flight operations practices were in accordance with the BCFS *Firebombing Procedures Manual*, with the exception that the Electra turned left before attaining sufficient altitude to avoid the rising terrain.

The report based on the internal examination by BFCS recommended that the BCFS firebombing training and procedures be reinforced so that, if tanker pilots choose to take an exit or line that is different from that demonstrated by the bird dog aircraft, they must advise the bird dog crew to allow them the option of re-checking the proposed (new) route for hazards. It was further recognized that bird dog and tanker aircraft may differ substantially in flight performance, and that, accordingly, the Spring 2004 operational air attack training sessions should focus on safety procedures and potential risks in the low-level firebombing environment.

BCFS aviation occurrence information reveals several instances where tanker pilots have been reticent to dump the retardant load and crashed as a result. On the other hand, there are data to show that releasing the load has prevented an occurrence. Although in this accident the pilots using the emergency dump mechanism would have had little effect on the outcome, the BCFS also recommended that pre-season training and operational practices conducted by their aircraft operators include the practical use of the aircraft emergency dump systems.

Crew Resource Management (CRM) training was introduced in the BCFS air tanker program in 1993, and the success of this program initiative is evident in that no serious injury had occurred since. Further, BCFS has developed an effective pilot/crew decision-making (PDM) program tailored to fire and forestry aviation operations. BCFS believes that such workshops and training are essential for safe fire-management aviation operations in British Columbia and recommended that the air tanker operators continue to provide initial and refresher CRM and PDM training to their pilots.

BCFS's Aviation Management Division actioned the recommendations outlined above in the following manner:

- At the April/May 2004 operational air attack training sessions, the firebombing procedures were reinforced, as well as the priorities of runs and exits, specifically in situations where tanker pilots choose to take a different exit or line. They must advise the bird dog crew to allow them the option of re-checking the proposed route for hazards.

- The pre-season training and operational practices conducted by contracted pilots include the practical use of the aircraft emergency dump systems.

- The BCFS Air Tanker Program and the air tanker operators are actively monitoring the delivery of initial and refresher PDM and CRM training to all pilots and air attack staff in the British Columbia program.

Air Spray

As a result of this accident, and commencing with its 2004 annual pilot training course, Air Spray has placed additional emphasis on human factors and emergency manoeuvring in mountainous areas. Particular attention has been given to the deceptive nature of mountainous terrain at high sun angles, and the deceptive illusionary nature of mountain flying continues to be stressed in its training programs.

This report concludes the Transportation Safety Board's investigation into this occurrence. Consequently, the Board authorized the release of this report on 07 September 2004.