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1010-CH147F-197571 (DFS 2-5-3)

7 October 2024

CH147310

Flight Safety Investigation Report

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CANADIAN ARMED FORCES
FLIGHT SAFETY INVESTIGATION REPORT (FSIR)

FILE NUMBER:	**1010-CH147F-197571 (DFS 2-5-3)**
FSIMS IDENTIFICATION NUMBER:	**197571**
DATE OF REPORT:	**7 October 2024**
OCCURRENCE CATEGORY:	**"A"**
AIRCRAFT TYPE:	**CH147F Chinook**
AIRCRAFT REGISTRATION NUMBER:	**CH147310**
DATE OF OCCURRENCE:	**20 June 2023**
TIME OF OCCURRENCE (L):	**0008 (L)**
LOCATION:	**CFB Petawawa, ON**
OPERATOR:	**450 THS, CFB Petawawa**

SYNOPSIS

On the evening of 19 Jun 2023, the crew of *Hammer 31*, on board aircraft CH147310, was scheduled to conduct two Advanced Night Tests as part of the Tactical First Officer Course. The flight was planned for a total of four hours, with each test taking two hours to complete. The two Student Pilots undergoing training conducted a crew change at the halfway point of the four-hour mission. The Instructor Pilot and the two Flight Engineers remained on board for the complete duration of the mission. The accident occurred during the second portion of the mission, shortly after the two Student Pilots' crew change. Two pilots and two Flight Engineers were on board the aircraft at the time of the accident.

The accident crew departed from Final Approach and Take-Off Area 17 to fly to confined area T40 in training area "E". Shortly after departure the Instructor Pilot simulated an engine chip emergency, which required the aircraft to return for landing. After the emergency scenario was completed, the crew departed again from Final Approach and Take-Off Area 17 to fly to confined area T40. During the turn towards confined area T40, the aircraft started to descend. While descending and still established in the left turn, the helicopter impacted the Ottawa River with high energy.

The helicopter was destroyed. The two pilots were fatally injured in the accident while the two Flight Engineers successfully egressed the helicopter, receiving only minor injuries.

The investigation determined that when the crew initiated the turn towards area T40, the aircraft entered a constant descent. None of the crew members realized the height and/or rate of descent of the aircraft before impact, resulting in a Controlled Flight into Terrain (CFIT) accident. It was concluded that the unperceived acceleration and the environmental conditions that night were key factors that played a role in this accident, contributing to the spatial disorientation experienced by the crew.

The investigation made numerous recommendations to amend the CH147F publications, including a recommendation to mandate the use of automation Level-3 (Native mode Digital Automatic Flight Control System) when operating below 200 ft above water at night. Additional recommendations were made to improve emergency response preparedness.

TABLE OF CONTENT

1. FACTUAL INFORMATION

1.1 HISTORY OF FLIGHT

1.1.1 On the evening of 19 Jun 23, Chinook aircraft CH147310, call sign *Hammer 31*, departed the Petawawa Heliport (CYWA) around 2155 local[1] (L). The crew was conducting an Advanced Night Test (ANT) as part of the Tactical First Officer (TAFO) Course, which was to be administered to each Student Pilot (SP) on separate two-hour flights. The Instructor Pilot (IP) and the two Flight Engineers (FE) were to remain on board for the entire four-hour mission with the SPs swapping on the ground after the first test was completed. Each test profile included various takeoffs and landings, simulated emergencies, tactical navigation, confined area landings, and slinging operations. The accident occurred during the second portion of the mission, after the "hot turn[2]" of the two SPs which occurred around 2345 L. There were four crew members on board.

1.1.2 When the SP took position in the right seat after the hot turn, the IP started to quiz the SP and then proceeded with the "*Before Taxi Check*"[3]. During this check the setting of the Radar Altimeter (RADALT) low altitude warning index, or RADALT bug, was omitted. While taxiing to the Final Approach and Take Off Area (FATO[4]) 17 for departure, the crew set up their Night Vision Goggles (NVG), commonly referred to as the "Goggle Up" procedure. The crew briefed a departure for a tactical navigation leg direct to the T40 confined area in training area "E", at a planned groundspeed of 90 knots. They departed FATO 17 to the south with a left-hand turn northbound towards T40. Shortly after departure the IP simulated a #1 Engine Chip[5] emergency, which led to a landing back to FATO 17. In preparation for the landing, the RADALT bug was set to 125 ft Above Ground Level (AGL). During the approach the low altitude audio caution from the RADALT sounded. It was verbally acknowledged and cancelled by the SP. The landing was completed successfully. This first leg of the mission is shown in blue in Figure 1.

1.1.3 The crew briefed another departure "as previously briefed" direct to T40, the second leg of the flight is depicted by the red line in Figure 1. After completing a vertical departure southbound, the IP simulated an NVG failure[6] for the SP, at which time controls were passed to the IP. The IP announced and initiated a left-hand turn

[1] Local time was on Eastern Daylight Time (EDT), which is four hours behind Coordinated Universal Time (UTC).

[2] Hot turn: procedure allowing for crew changes without shutting down the aircraft engines.

[3] C-12-147-F00/MB-001 - Aircraft Operating Instructions, para 2A-2-16.

[4] The FATO is the area over which the pilot completes the final phase of the approach to a hover or a landing.

[5] A magnetic chip detector is normally used to monitor engine or transmission metal particles in the oil, which can provide an early warning of an impending failure.

[6] NVG failure simulation is achieved by having a crew member manually switch off the NVG of another crew member. The NVG battery switch is located on the battery pack which is fixed on the back of the helmet.

northbound. Upon regaining NVG, controls were transferred back to the SP while still in the left-hand turn; at approximately a third of the planned 150 degrees turn. The IP then advised the SP of a Trim Roll Right advisory which the SP attempted to rectify once without success (1.6.15). The crew then conducted the *Before Landing Check*[7], and the IP briefed navigation instructions to T40. Speed and altitude were briefed to be at the SP's discretion, and as the navigation details were being discussed between the pilots, the low altitude audio caution from the RADALT sounded and was promptly cancelled by one of the pilots with no acknowledgement or corrective actions. The aircraft decelerated slightly, and the Cabin Door FE called "*Height, 20 ft above water*". The aircraft impacted the Ottawa River at 00:08 L on 20 Jun 23, approximately 1.5 km from their departure point.

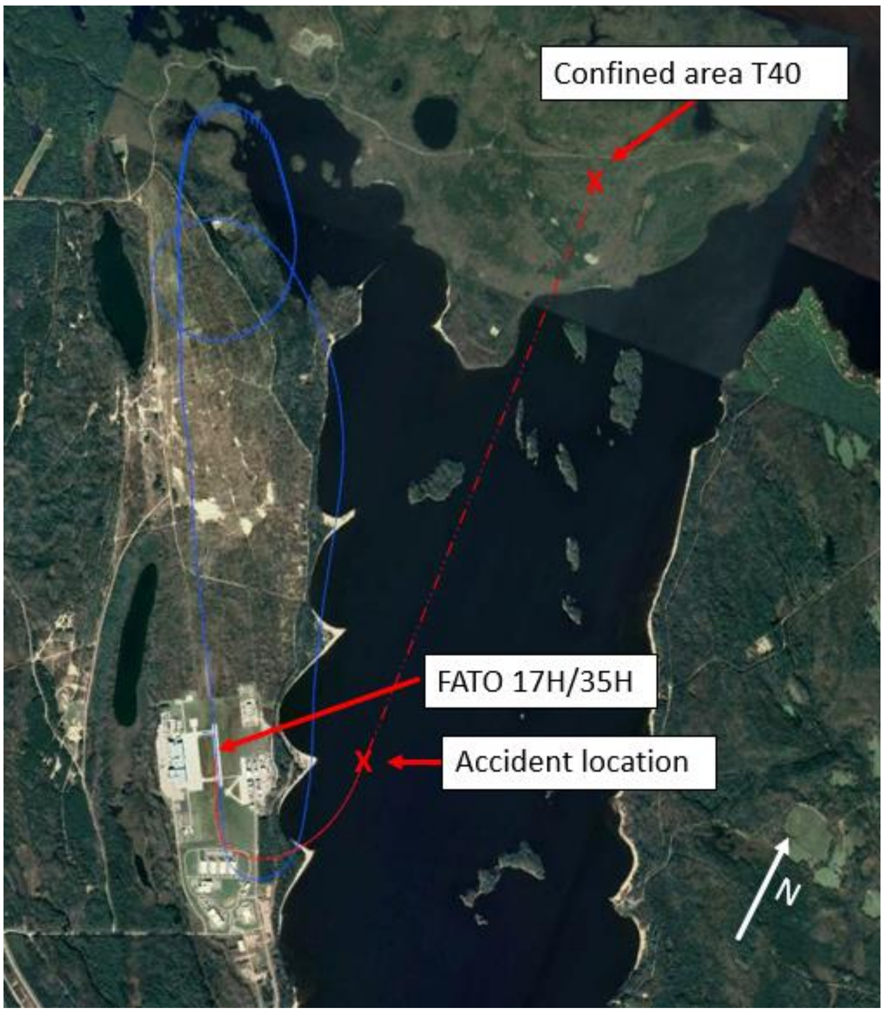

Figure 1 - Map showing the first leg (Blue) and the second leg (Red) for accident flight

[7] C-12-147-F00/MB-001 - Aircraft Operating Instructions, para 2A-2-30.

1.2 INJURY TO PERSONNEL

1.2.1 The two pilots were fatally injured in the accident and the two FEs successfully egressed the sinking helicopter, receiving only minor injuries.

1.3 DAMAGE TO AIRCRAFT

1.3.1 The aircraft was destroyed (A Category) due to the high impact force with the water. Damage was found to the cockpit area, the cabin floor, the front right-hand sponson, the right-hand fuel tank area, the front landing gear, the rotor blades, the aircraft under belly and the engines.

1.3.2 Both engines sustained impact damage. A visual inspection of the engines was conducted, including the engine intake and turbine sections. No anomalies were noted.

1.4 COLLATERAL DAMAGE

1.4.1 After the impact with the water, and because of the river current, aircraft debris was distributed downstream of the accident location. The debris was recovered, and daily uncrewed aircraft vehicle (UAV) patrols were conducted to identify any further items for collection.

1.4.2 A floating retention boom downstream of the site to capture any escaping petroleum, oils, and lubricants (POL) was set-up approximately two hours after the accident. A civilian environmental protection company was immediately contracted to install POL collection devices to further minimize any potential waterway contamination and remained on-site to monitor the protective measures until the aircraft wreckage was removed from the water. UAV patrols were conducted and identified several potential contaminated locations. These were all tested and cleared. As a precaution, water was tested daily. After the testing was completed, the environmental impact was determined to be negligible.

1.4.3 Upon raising the aircraft wreckage, a small amount of POL escaped. Any POL loss was mitigated with the use of a retention boom and absorbent materials. The aircraft was floated and towed to shore with the use of a secondary boom. The shore was protected with beach hazardous material protective equipment and a third retention boom was used to secure the aircraft anchored 5 m offshore. The aircraft was then defueled, a small loss of POL was contained with the use of fuel absorbing materials. Upon aircraft removal from the water the third retention boom area was cleaned of hazardous fluids. The loss of POL in the recovery process was deemed to have a negligible environmental impact.

1.5 PERSONNEL INFORMATION

GENERAL

1.5.1 The flight was authorized, and the crew was qualified and current for the assigned mission.

1.5.2 The crew complement consisted of an Aircraft Captain (AC), a First Officer (FO), and two FEs. As the occurrence flight was an instructional trip, the AC was the IP, and the FO was the SP. Irrespective of the above titles, the pilot in control of the aircraft is the Pilot Flying (PF) and the other pilot is the Pilot Monitoring (PM). All crew members were from 450 Tactical Helicopter Squadron (THS).

1.5.3 The AC was a multi-tour 1 Wing pilot with experience on the CH135 Twin Huey, the CH146 Griffon, and most recently the CH147F Chinook. The AC joined 450 THS in 2016 and had flown 1040.7 hours (hrs) on the CH147F, for a total of 6770.7 hrs of military flying. Most of the IP's flying career was spent in Petawawa. The AC was qualified as a Flight Lead, a Standards Pilot, and an IP – Level A, an Instrument Check Pilot, and a Flight Simulator Instructor. The AC occupied the left cockpit position, as the IP during the sortie.

1.5.4 The FO was a first tour 1 Wing pilot who joined 450 THS in 2019 and had flown 185.6 hrs on the CH147F, with a total of 445.2 hrs of military flying. The accident flight was the SP's final test for the CH147F TAFO Course. The FO occupied the right cockpit position, as the SP during the sortie.

1.5.5 The FE positioned at the cabin door (near the cockpit) was a first tour 1 Wing FE who joined 450 THS in 2021 and had flown 657.7 hrs on the CH147F. This FE was a Qualified Instructor FE and had been a late addition to the flight early in the evening of 19 Jun 23.

1.5.6 The FE positioned at the cargo ramp (left side rear) was a multi-tour 1 Wing FE with experience on the CH146, the CH178[8] and CH147F. This FE joined 450 THS in 2016 and had flown 1225.6 hrs on the CH147F, with a total of 5880.5 hrs of military flying. This FE was an experienced Standards qualified FE.

1.5.7 Table 1 reflects the flying hours and currency status for each crew member of *Hammer 31*.

[8] Before the purchase of CH147 Model-D aircraft, the RCAF operated the Mi 17 aircraft (as CH178) to support operations in Afghanistan.

	AC	FO	Cabin Door FE	Ramp FE
Total Flying Time Hours (Military)	6770.7	445.2	657.7	5580.3
Flying Hours on Type	1040.7	184.3	657.7	1225.6
NVG Hours	1409.5	59.9	182.9	1393.5
Flying hours Last 30 Days	10.4	16.1	31.8	20.4
Flying Hours Last 90 Days	32	31.8	83.7	57.2
Duty Hours – Last 48 Hours	7.1	7.1	6.6	5.3
Duty Hours – Day of Occurrence	7.1	7.1	6.6	5.3
Annual Proficiency Check	Valid	N/A (Student Pilot)	Valid	Valid
Currency	Valid	N/A (Student Pilot)	Valid	Valid
RUET[1] Completed[9]	Valid 12 Jul 17	Valid 21 Nov 22	Valid 17 Dec 21	Valid 01 Nov 17
Medical Category	Valid	Valid	Valid	Valid

Table 1: Crew flying hours and currency

Student Pilot Course Progression

1.5.8 The FO course consists of the first Module called Basic First Officer (BFO) and the second Module called TAFO, with each Module holding their own Military Individual Training and Education Code. For ease of reading, the remainder of the report will use the terminology of BFO course and TAFO course. The SP BFO/TAFO course progression was assessed using their progress book (Prog Book). The graphs depicting course progression and continuity for all SPs on BFO 2102 and TAFO 2202 are included at Annex D while the graphs depicting instructor continuity are included at Annex E. Out of 15 flights conducted in low illumination conditions for the SP, six (6) were carried out at illumination levels below 0.85 millilux (mlx). The BFO/TAFO course syllabus has no specific training requirement related to the *Black Hole Effect* (see 1.18.17), and the Prog Books did not specify if this condition was encountered during the SP's training.

[9] RUET: Rotary-Wing Underwater Escape Training; Maximum validity period: 10 years.

1.5.9 A review of the SP's Prog Books revealed that they had failed to meet the standard on the BFO Basic Night Test on two occasions in Oct 22. The occurrence SP was not the only pilot who had difficulties in the BFO basic night phase. In fact, three of the four SPs on the course failed to meet the standard on at least one flight during that phase. A closer review of the occurrence SP's progress cards (Prog Card) revealed that their difficulties were related to the ineffective use of visual references in the hover using NVG. The investigation determined that the SP's difficulties were not related to the accident flight scenario and concluded that these were not causal.

FATIGUE ASSESSMENT

1.5.10 The Fatigue Avoidance Scheduling Tool (FAST) is software developed for industry, military and sports. It is used to estimate the impact of human fatigue risk in schedule and roster design. The software is based on an algorithm developed by the Walter Reed Army Institute of Research. Within this model, human fatigue is considered to have a significant negative effect on an individual's performance at an approximate score of 77% effectiveness or less. As seen in the following table, at the time of the accident the model estimates the human fatigue risk to be Low for each crew member of *Hammer 31*.

	IP	SP	Cabin Door FE	Ramp FE
FAST Score	89.4%	101.1%	90.1%	95.8%

Table 2: FAST results

1.5.11 The Fatigue Risk Management System is a Risk Management process that applies to all personnel involved in air operations or the support of air operations. A Fatigue Assessment Report (FAR) is filled by each crewmember prior to the commencement of a daily mission or work/duty cycle, to determine fatigue risk. Each crew member of *Hammer 31* had a FAR score between 0 to 5, which corresponds to a Low Fatigue Risk.

1.6 AIRCRAFT INFORMATION

1.6.1 The Boeing CH147F Chinook is a twin-engine, tandem rotor helicopter designed for transportation of cargo and troops during day, night, visual, and instrument flight conditions. It has a maximum occupancy of 37 (33 passengers and four crew). The helicopter is powered by two Honeywell T55-GA-714A turboshaft engines mounted on each side of the helicopter's rear pylon. The engines simultaneously drive tandem three-bladed counter-rotating rotors through a series of transmissions and drive shafts. The CH147F is equipped with long-range fuel tanks carried in pods on either side of the fuselage. An entrance door is situated along the forward right side of the cargo compartment (Cabin Door). An escape hatch is situated along the forward left side of the cargo compartment (Door Gunner Window). A hydraulically operated loading ramp (Cargo Ramp) is located at the rear of the cargo compartment.

1.6.2 Aircraft CH147310 was delivered from Boeing to the Royal Canadian Air Force (RCAF) in 2014 and had a valid certificate of airworthiness on the day of the accident.

1.6.3 The aircraft was loaded with 12500 lbs of F37 fuel for the mission. There was an estimated 8000 lbs of fuel remaining at the time of impact. Weight & Balance calculations demonstrated that the aircraft was operating within Center of Gravity limits, both at take-off and at the time of the accident.

1.6.4 Records indicated that the aircraft was maintained in accordance with the approved maintenance program. The aircraft was serviceable when it was released for the mission, and there was no mention of any concerns or unserviceability by the crew.

AIRCRAFT FLIGHT CONTROLS

Thrust Control Lever: Magnetic Brake (MAG BRAKE) Switch

1.6.5 A thrust brake switch, commonly referred to as the "MAG BRAKE" switch, is located under the grip handle of each thrust control lever which is sometimes referred to as the collective (Photo 1). The MAG BRAKE switch controls the magnetic brake of the thrust Cockpit Control Drive Actuator (CCDA). When the pilot's left hand is resting on the grip handle, the switch is activated by the index finger via a trigger-like mechanism. Pressing the switch applies electrical power to release the magnetic brake in the CCDA, allowing the thrust control lever to be moved freely up or down. When the switch is released, the magnetic brake is applied, holding the thrust control lever in position. If the thrust CCDA fails, the thrust control lever will slip when a force greater than seven pounds is applied[10].

Photo 1 - Thrust Brake Switch (Side view)

[10] C-12-147-F00/MB-001 - Aircraft Operating Instructions, para 8-9-2-1.

Cyclic: Acknowledge (ACK) Switch

1.6.6 An acknowledge switch, commonly referred to as the “ACK button” is located on each pilot cyclic grip (Figure 2). The ACK switch enables the pilots to acknowledge an active MASTER CAUTION annunciator light and to mute present Voice Warning System (VWS) messages.[11]

Cyclic: Centering Device Release (CD REL) Switch

1.6.7 The CD REL switch is located on each pilot cyclic grip (Figure 3). Pressing the CD REL switch disengages the force feel trim magnetic brakes for the lateral & longitudinal (i.e. cyclic), and directional (i.e. pedals) flight controls. This allows for free movement of the cyclic stick and rudder pedals to enable new pitch, roll and yaw datums to be rapidly established. Upon releasing the CD REL switch, the magnetic brakes are re-engaged thus re-initializing the cyclic stick and rudder pedal position datum. The new pitch, roll and yaw attitude datums are taken as those existing when the CD REL switch is released, effectively recentering the controls. This new position for the centering springs can be overridden by the pilot while manoeuvring the helicopter.

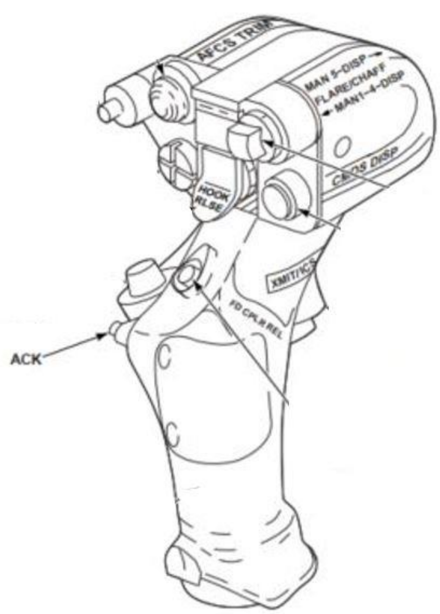

Figure 2 - Cyclic Grip ACK Switch[12]

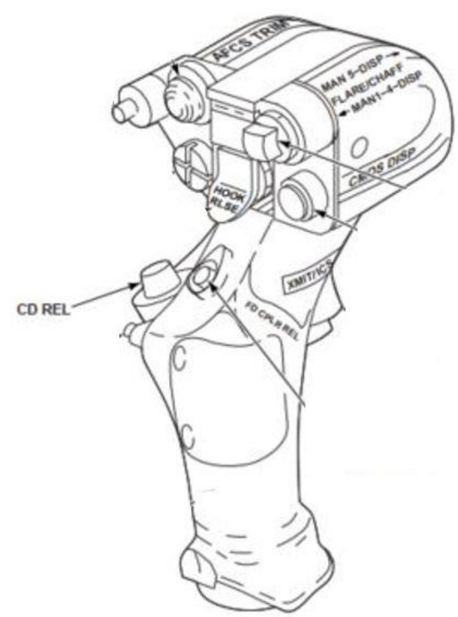

Figure 3 - Cyclic Grip CD REL Switch[13]

AIRCRAFT INSTRUMENTATION

1.6.8 The instrument panel in front of each pilot station includes two Multi-Function Displays (MFD), see Figure 4. With weight-off-wheels, at least one of the two MFDs will always display a Primary Flight Display (PFD).

[11] C-12-147-F00/MB-001 - Aircraft Operating Instructions, para 8-9-3-2.e.
[12] C-12-147-F00/MB-001 - Aircraft Operating Instructions, Figure 8-9-2 (Modified).
[13] Ibid.

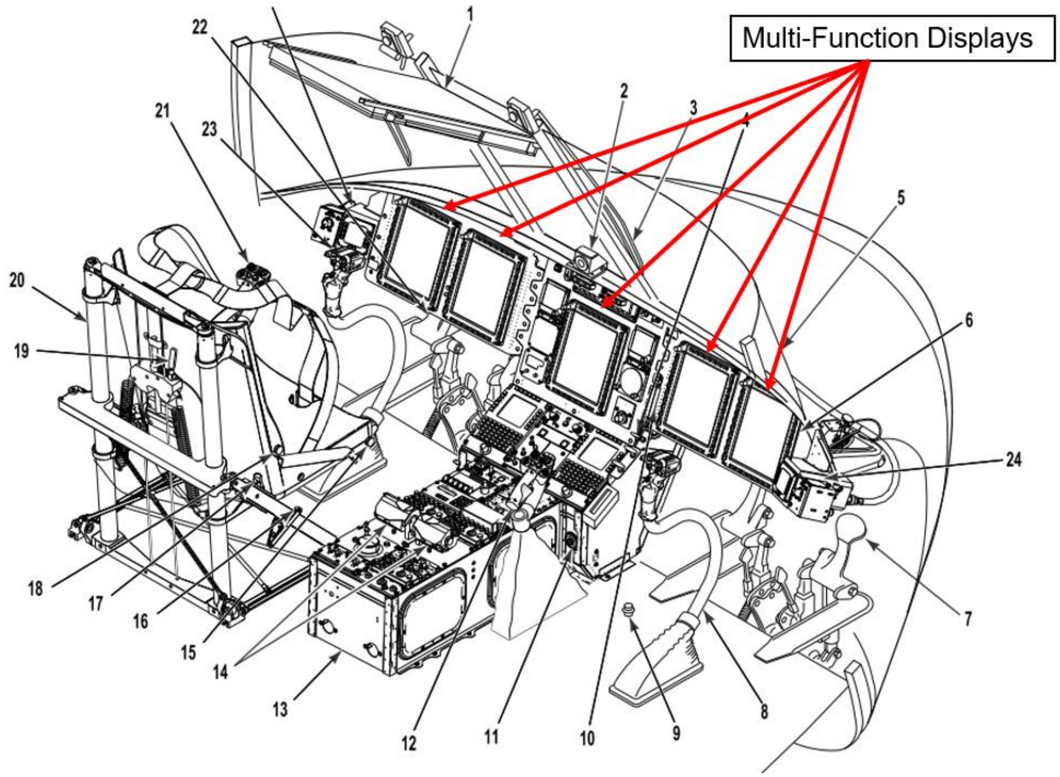

Figure 4: View of CH147F Cockpit and MFDs' location [14]

Altimeter

1.6.9 The aircraft altitude, based on either Global Positioning System (GPS) or barometric information, is represented by the altitude indicator display on the PFD (Figure 5). The altitude indicator includes a dynamic graphical tape and a roll-over style digital presentation of the sensed altitude. The graphical tape has a range of -1000 to 25000 ft and will scroll vertically to align with changes in the sensed altitude value. The currently sensed value for altitude is displayed at the tape location where the tip of the digits box is pointing.

1.6.10 There is also an altitude digital readout on each of the two standby flight displays located on the centre instrument panel on the left and right side of the centre MFD (Figure 4: View of CH147F Cockpit and MFDs' location Figure 4).

[14] C-12-147-F00/MB-001 - Aircraft Operating Instructions, Figure 8-1-5.

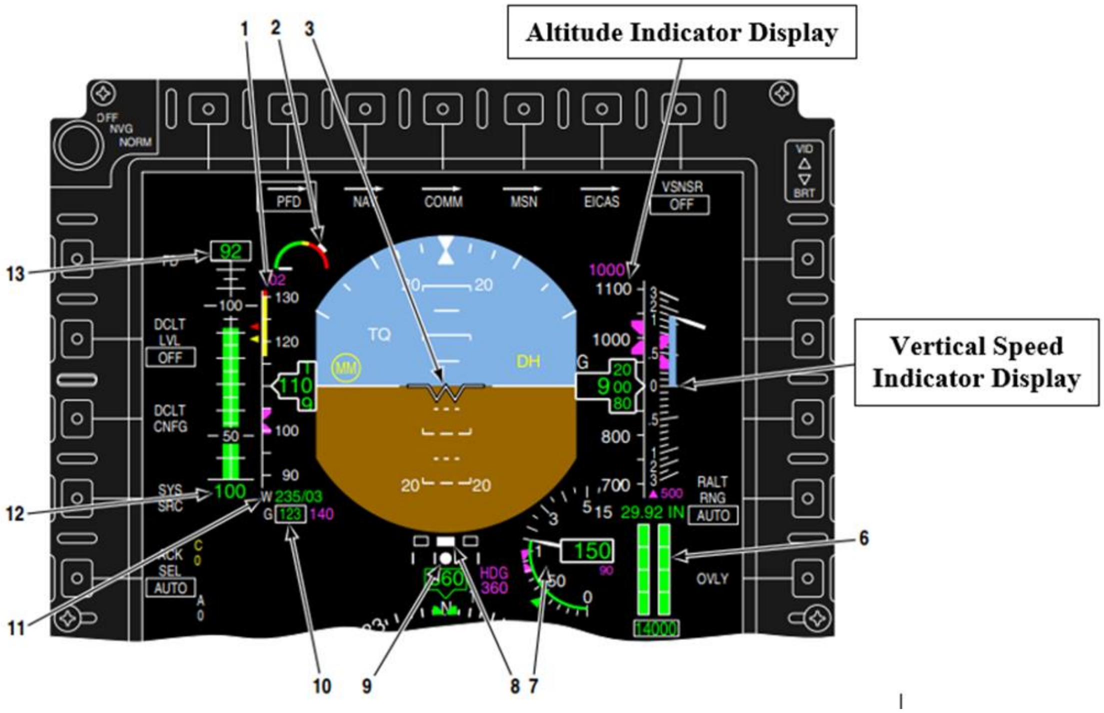

Figure 5 - CH147F Altitude Indicator and Vertical Speed Indicator Displays on the PFD[15]

Vertical Speed Indicator (VSI)

1.6.11 The aircraft rate of climb or descent is indicated by the VSI in units of feet per minute (fpm). The VSI is displayed on the PFD (Figure 5) and on both standby flight displays; the vertical speed information is displayed using a needle and a fixed scale. For the VSI on the PFD, in addition to the vertical speed needle, a vertical speed drag line is provided to reinforce the sense of the current vertical speed value. The dynamic drag line follows the vertical speed needle and is cyan to indicate climb and brown to indicate descent.

Radar Altimeter (RADALT)

1.6.12 The RADALT constantly senses and provides radar altitude as height AGL measured in feet. RADALT information is displayed on both PFDs (Figure 6) as well as on the RADALT instrument located in the middle section of the instrument panel. The RADALT instrument is visible from the cabin when a crew member positions themselves in the companionway[16]; this is a common method available for the FE to monitor altitude using instruments. RADALT depiction in the Heads-Up Display (HUD) will be covered in

[15] C-12-147-F00/MB-001 - Aircraft Operating Instructions, Figure 8-18-8 & 8-18-10.
[16] The companionway is the corridor between the cockpit and the cabin.

the HUD symbology portion of this report (1.18.8). The PFD displays RADALT height information in three ways:

- The RADALT pointer;
- The drag line tape; and
- The digital readout window.

1.6.13 The RADALT also has a low altitude warning index, known as the "RADALT bug" (Figure 6). The RADALT bug is set by either pilot based on the flight profile being flown. When the aircraft descends below the altitude set on the RADALT bug, the aircraft will provide an alert consisting of an aural tone (ping) followed by the verbal warning "*Altitude*". This alert will be repeated at an interval of 1.7 seconds until it is acknowledged by one of the pilots (Figure 7). To acknowledge and cease the alert, one of the pilots must press the cyclic ACK switch (1.6.6).

1.6.14 The RADALT bug is verified as part of the aircraft "Systems Check", which is detailed in the Aircraft Procedural and Emergency Checklist[17]; this portion of the checklist does not have to be verbalized. The following checks include an aircraft "Systems Check"; hence the crew is required to verify the RADALT and set the bug at the desired altitude:

- *Before Taxi Check*;
- *Before Take-Off Check*; and
- *Before Landing Check*.

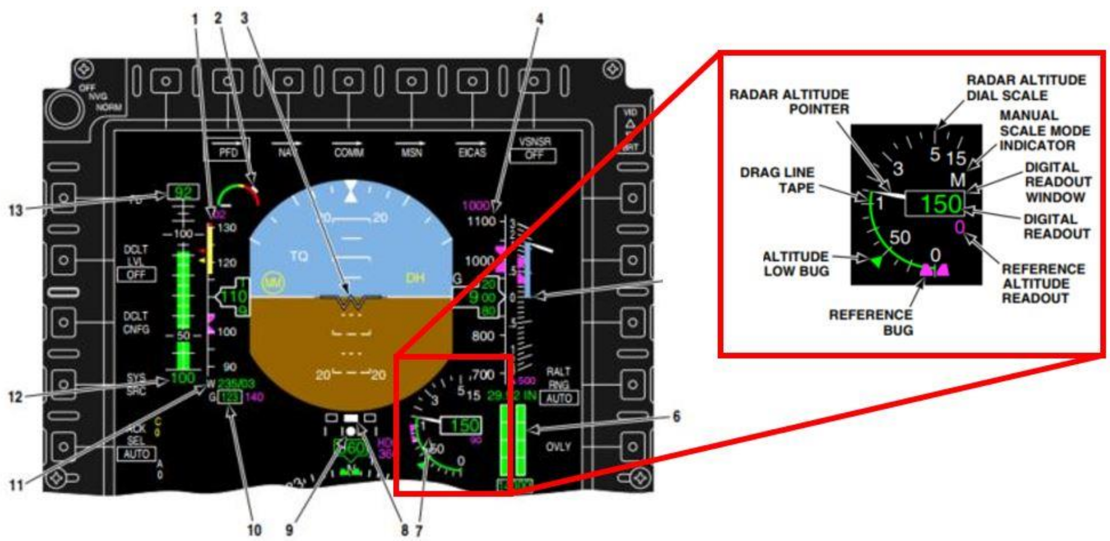

Figure 6 - CH147F RADALT Display on the PFD[18]

[17] C-12-147-F00/MC-001 – Aircraft Procedural and Emergency Checklist, page P-21.
[18] C-12-147-F00/MB-001 - Aircraft Operating Instructions, Figure 8-18-8 & 8-18-10.

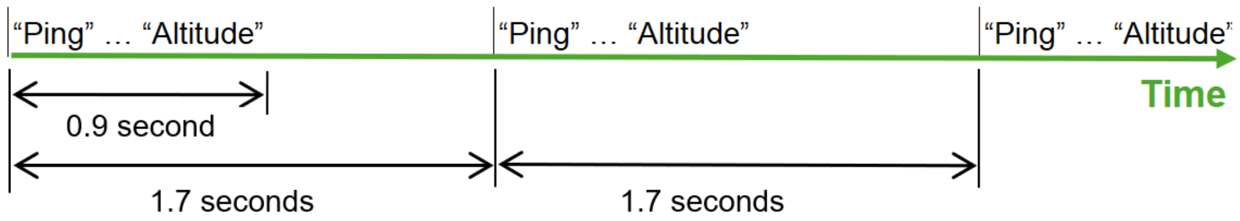

Figure 7: Timeline for the Low Altitude warning cycle

TRIM ROLL LEFT/RIGHT ADVISORY

1.6.15 The Trim Roll (left or right) Advisory[19] is displayed on the MFD located in front of the pilots on either side of the instrument panel. The advisory signifies that the roll Integrated Lower Control Actuator (ILCA) is biased by more than 50%. If left unattended, a large bias could lead to ILCA saturation and a loss of control authority. The corrective actions are detailed in the Aircraft Operating Instructions (AOI)[20], which state that the PF should respond to these advisories by pressing the CD REL switch (Figure 3) and move the cyclic stick laterally 1/2 to 1 inch in the direction indicated by the advisory (left or right). Following the corrective actions, the PF will verify if the advisory has been cleared by looking at the MFD.

AIRCRAFT PERFORMANCE

Calculated Safe Single-Engine Speed

1.6.16 Calculating the safe single-engine speed requires the use of pressure altitude which also requires calculation. Using the altimeter setting provided to *Hammer 31* by the Military Flight Advisory Unit (MFAU)[21] (1.7.1) and the Petawawa Heliport airfield elevation (1.10.1), the pressure altitude was calculated using the formula:

$$\text{Pressure Altitude} = (29.92 - \text{Altimeter Setting}) \times 1000 + \text{Elevation}$$

1.6.17 The pressure altitude was calculated to be 197 ft. From the pressure altitude, the investigation calculated the safe single-engine speed to be 30 knots indicated airspeed (KIAS). The safe single-engine airspeed is the airspeed at which the aircraft is designed to be able to maintain continued level flight on a single engine. It is also used to determine the requirement for aircrew floatation devices during overwater flight (1.15.43).

[19]An advisory is an informational indication of a condition or state requiring aircrew awareness. Continued flight or mission conduct in conditions characterized only by advisories is not specifically restricted. Advisories are less critical than Warnings and Cautions.
[20] C-12-147-F00/MB-001 - Aircraft Operating Instructions, Paragraph 8-9-12. f.
[21] Termium: MFAU is a military ground station established to provide enroute flight information, airport advisory, ground control, field condition reports, flight planning, alerting service, navigation assistance, NOTAMs [notices to airmen], PIREPs [pilot weather reports] and weather reports.

AIRCRAFT AUTOMATION

1.6.18 The aircraft is equipped with four levels of automation. Figure 8[22] shows these four levels as well as their hierarchy. The first level is the Core Mode Digital Automatic Flight Control System (DAFCS). This level of automation is the most basic and least automated mode. It allows for the aircraft to be hand-flown while still benefiting from the stability provided through the DAFCS. At the time of the accident the aircraft was flown using the Core Mode DAFCS.

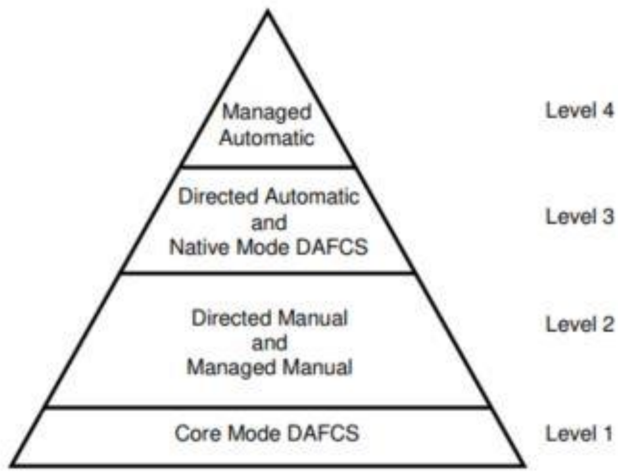

Figure 8 - CH147F Levels of Automation

1.7 METEOROLOGICAL INFORMATION

1.7.1 The weather on the night of the accident was Visual Meteorological Conditions (VMC)[23]. There was low illumination, with calm winds and a temperature of approximately 13 degrees Celsius (°C). No Meteorological Terminal Air Report (METAR) data was available at the time of the accident, however the Terminal Area Forecast (TAF) called for no ceilings, and visibility greater than 6 statute miles (sm) at the time of the accident (0408Z). Based on radio communications between *Hammer 31* and the MFAU the altimeter setting was 30.15 inches of mercury (inHg).

1.7.2 The last METARs produced by the 450 THS Met Section were as follows:

[22] B-GA-002-147/FP-001, CH147F Chinook Standard Manoeuvre Manual (SMM), Chapter 1, para 71.
[23] Termium: Meteorological conditions expressed in terms of visibility, distance from cloud, and ceiling, equal to or better than specified minima.

METAR CYWA 191800Z 11006KT 10SM FEW040TCU BKN090 24/14 A3007 RMK TCU2AC4 DENSITY ALT[24] 1574FT SLP181 57004 SKY6 T02360139=

METAR CYWA 191900Z 13005KT 090V150 10SM SCT045TCU BKN090 25/14 A3006 RMK TCU3AC4 DENSITY ALT 1754FT LAST OBS /NEXT 201200 UTC SLP179 SKY7 T02500144=

1.7.3 The last TAF was:

TAF CYWA 191740Z 1918/2018 09008KT P6SM FEW040 OVC090
TEMPO 1918/1919 P6SM -SHRA BKN040 OVC090
PROB30 1918/1919 2SM TSRA BR BKN040CB OVC090 FM191900
10005KT P6SM FEW040 OVC090
TEMPO 1919/1923 P6SM -SHRA BKN040 OVC090 FM192300 08005KT
P6SM BKN050
BECMG 2003/2005 FEW040 FM200600 VRB03KT P6SM FEW040
PROB30 2008/2011 1SM BR RMK NXT FCST BY 200000Z

1.7.4 The Petawawa Tactical Prognosis (included with the weather package - 1.7.6) provided to the crew showed no adverse weather in the area. This is consistent with the NAV Canada Graphical Area Forecast for the time of the accident.

1.7.5 The illumination level on the night of the flight was low. There was no moon at the time of the accident as it had set at 0253 Z (2253 L).

1.7.6 There was no meteorological technician on duty prior to the departure of the accident flight and a hard copy of the weather package was left at the Squadron Operations office for use by night-shift crews. The Aircrew Night Vision Imaging System (ANVIS) package produced covered the period from the first flight to 0700 Z (0300 L). At 0400 Z (0000 L) the corrected value[25] for the illumination level was 0.54 mlx. This correction was determined using a broken ceiling of 5000 ft, precipitation of isolated mist, and visibility less than 3 sm in mist. This illumination level was calculated using the approved Web ANVIS Version 4.1.2 website, which is a tool commonly used by RCAF aircrews. The application was originally developed by the Royal Canadian Navy (RCN) and was supported until 2013. Since then, ANVIS support has been provided by the Joint Met Centre (JMC) in Gagetown and by Defence Informatics Services (supporting DND). Contact information within ANVIS still lists outdated RCN contacts, but this is being rectified. The program remains available for use through the Canadian Forces weather office website (https://met.forces.gc.ca/).

[24] ALT: Altitude.
[25] The ANVIS tool provides illumination levels based astronomical data, which can be corrected by manually entering cloud and weather inputs.

1.8 AIDS TO NAVIGATION

1.8.1 The accident flight was conducted in VMC under Visual Flight Rules (VFR), such that NVG (1.18.1) and the GPS enabled moving map on the MFD(s) were the only aids to navigation and positional awareness; with the aircraft operating at the lowest level / Core Mode of automation (1.6.18).

1.9 COMMUNICATIONS

1.9.1 At the time of the accident, flight following and communication services were being provided by the MFAU (1.10.2).

1.9.2 Shortly after *Hammer 31*'s departure from FATO 17, the MFAU advised them of the location of *Hammer 32*, which was operating to the East of the heliport. This was the last communication with *Hammer 31*. No concerns with aircraft handling or performance were communicated by *Hammer 31* to either *Hammer 32* or the MFAU.

1.9.3 There was no Mayday or Pan-Pan call made by *Hammer 31*. A Mayday call was transmitted to the MFAU eight seconds after water impact by *Hammer 32,* who witnessed the accident.

1.10 AERODROME INFORMATION

1.10.1 The Petawawa Heliport (CYWA) has a FATO located on Garrison Petawawa. FATO 17H/35H is 1630 ft long, 160 ft wide and has a paved surface, with headings of 165 degrees and 345 degrees magnetic, respectively. The FATO has both visual and Infrared (IR) lighting, with a field elevation of 427 ft Above Sea Level (Figure 9). The Ottawa River runs approximately North-South and is located just to the east of the airfield. The river is approximately 20 ft lower than the airfield elevation and sits on the other side of a treeline.

1.10.2 Petawawa Heliport radio communications are managed by the MFAU. Although the MFAU is a component of 427 Special Operations Aviation Squadron (SOAS), it provides flight following and communication services for all aviation assets flying at Garrison Petawawa. 450 THS and 427 SOAS both operate from the Petawawa Heliport.

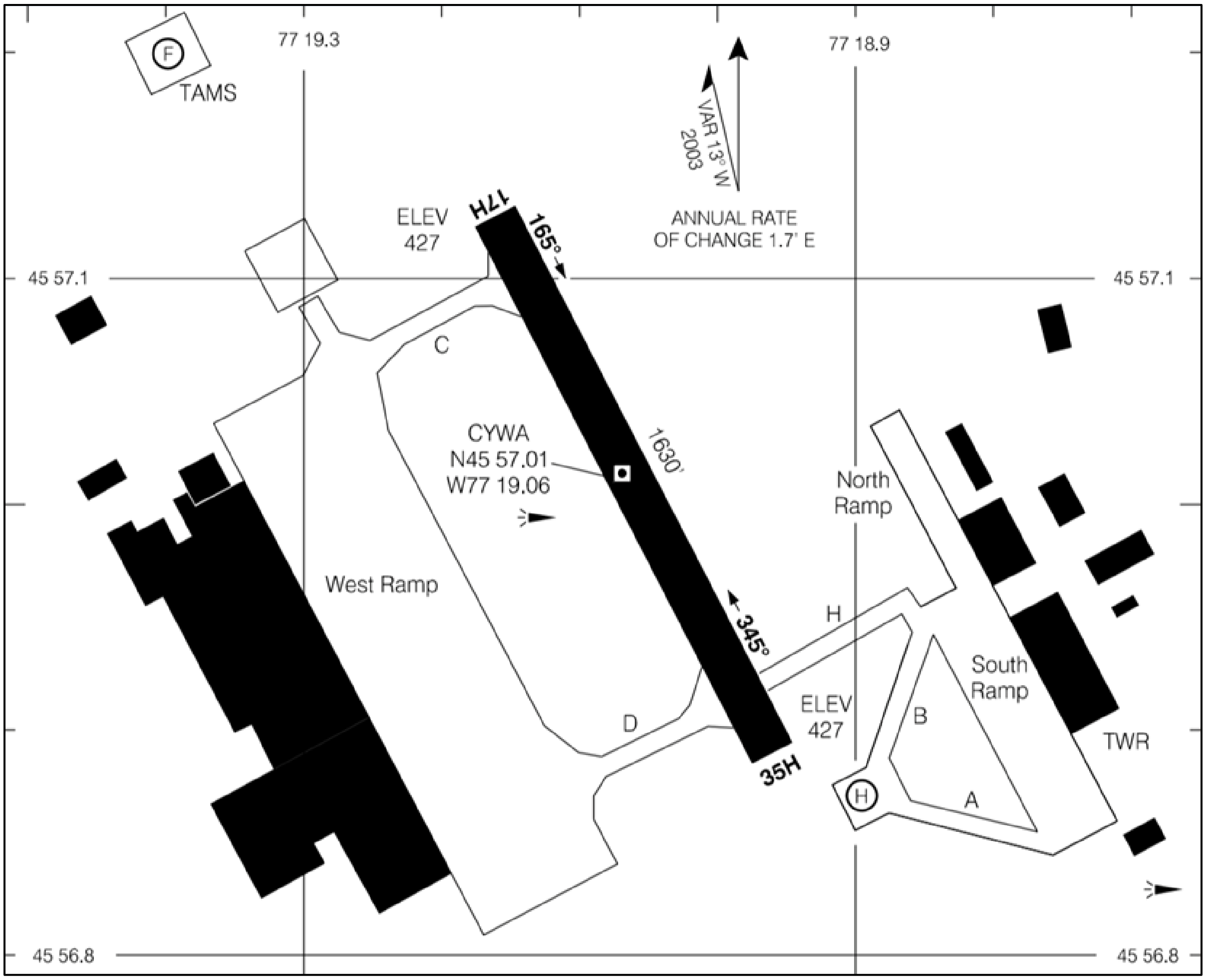

Figure 9 - Heliport Chart, Petawawa, ON, CYWA

1.11 FLIGHT RECORDERS

1.11.1 The CH147F is equipped with a crash survivable Cockpit Voice Recorder (CVR) and Flight Data Recorder (FDR). The unit can store up to two hours of voice audio and nine hours of flight data. Impact forces damaged the exterior of the CVR/FDR, allowing water ingress inside the unit. Using the recorder Original Equipment Manufacturer (OEM) recommended drying procedure, the National Research Council (NRC) was able to recover the data and make it available to the investigation.

COCKPIT VOICE RECORDER (CVR)

1.11.2 The CVR recording showed that the crew of *Hammer 31* had a heavy task load in the 61 seconds of flight that preceded the accident. Of particular note are the final 11 seconds, with many simultaneous communications occurring, with voices effectively "stepping" on one another. The following is a list of activities and tasks that took place in the final 61 seconds:

- Take-off from the FATO;
- Communicating with the MFAU;
- Back to cruise call;
- Simulated NVG failure scenario for the SP;
- Passing of controls from the SP to the IP;
- IP called and initiated a left turn;
- SP NVG regained;
- Passing of controls from IP to the SP;
- IP initiating the *Before Landing Check* in preparation for landing at T40;
- IP advising the SP of a Trim Roll Right Advisory;
- IP completing the *Before Landing Check*;
- IP providing navigational directions to the SP;
- RADALT low altitude warning sounded;
- RADALT low altitude warning sounds was muted using the ACK switch; and
- Cabin Door FE calling "*Height, 20 ft above water*".

1.11.3 The passing of controls from the IP to the SP, after the simulated NVG failure scenario, took place after the left turn to T40 had been initiated. The controls were transferred at around 45 degrees through the 150 degrees left turn, and at a bank angle of approximately 36 degrees. At that moment, the descent rate was approximately 300 fpm, and increasing.

1.11.4 The investigation also noted a few breaks and pauses in the speech of the IP. There was a minor error when the take-off advisory was made to the MFAU where the IP indicated taking off from FATO 35 when in fact it was FATO 17.

1.11.5 The RADALT low altitude warning occurred 7.4 seconds before impact; with the end of the automated verbal warning "*Altitude*" occurring 6.5 seconds before impact. The warning was not acknowledged verbally by any crew member, however, it was cancelled by one of the pilots using the ACK switch as the warning emitted only once and did not repeat for its second cycle (1.6.6, 1.6.13). The RADALT low altitude warning was heard during the first circuit back to FATO 17 (simulated engine chip scenario). In this instance, the RADALT bug was set to 125 ft and the warning was acknowledged and acted upon as per the Standard Manœuvre Manual (SMM).

1.11.6 The Cabin Door FE announcement of the aircraft's height above the water was made 2.0 seconds before impact.

FLIGHT DATA RECORDER (FDR)

1.11.7 The flight data was closely examined to see if there were any issues with the flight characteristics of the aircraft. The data showed no anomalous flight characteristics. The aircraft exhibited smooth and continuous motions throughout the final flight profile. After takeoff, the aircraft climbed to 315 ft AGL at a rate of up to 2000 fpm. Twenty-six seconds after takeoff, a left turn was initiated, and a small thrust control lever increase was applied as the maximum bank angle of 36 degrees was reached at 34 seconds. At 41 seconds, the bank angle was reduced to 25 degrees, and the aircraft reached a constant descent rate of 1000 fpm, which was maintained (+/- 200 fpm) until impact. Beginning at 45 seconds, the thrust control lever is continuously reduced until impact. At 54 seconds, the aircraft bank angle is further reduced to 15 degrees.

1.11.8 The FDR data showed that, at time of impact, the aircraft heading was 005 degrees magnetic, and that it was descending at approximately 800 fpm, in a left-hand turn with a bank angle of 18 degrees at 118 KIAS. In the final 7 seconds of flight, the aircraft pitched up from -2 degrees (nose low) to 4 degrees (nose up), and the airspeed reduced from approximately 127 KIAS to 118 KIAS. No large flight control inputs were recorded in the data. The aircraft experienced a force greater than 60 G[26] at the time of impact.

1.11.9 The flight data was also closely examined to determine if there were any performance and/or technical issues with the aircraft. The engines were performing as expected. An examination of the flight control parameters revealed rapid activation/deactivation of the thrust control lever's MAG BRAKE switch. Annex F shows the graph with the four MAG BRAKE channels depicted on a single chart. All four channels show the MAG BRAKE being activated in rapid succession, 15 times for the last 16 seconds of the flight just before impact. During this period, the thrust control lever was constantly lowered in small increments reducing torque values from approximately 59% to 18%.

1.11.10 The investigation obtained FDR information from the other aircraft in the fleet, spanning a total of 60 flights over a 27-day period. The data revealed a pattern of rapid succession MAG BRAKE applications amongst most crews and, to varying extents, on all mission profiles.

1.11.11 The investigation was interested in the RADALT bug setting(s); however, the value is not recorded on the CH147F FDR. Consequently, RADALT setting(s) were assessed by correlating CVR audio and FDR altitude information.

1.11.12 The flight path for *Hammer 31* was reconstructed using FDR data. Maps showing the flight path are included at Annex G. The investigation determined that the profiles flown by the first and second SP differed in that the first SP's profile was flown predominately over land, whereas the second SP profile brought the aircraft over the Ottawa River. Significant events of the accident flight (61-second leg for the second SP) were plotted against the flight path map. This map, which is overlaid with select FDR data flight parameters, is included at Annex G.

[26] The G-force is a mass-specific force (force per unit mass) expressed in units of standard gravity. For example, an object at rest is subject to 1G.

1.11.13 Additional information was obtained from the FDR data, which was relevant to the investigation:

a. From the FDR data, the investigation was able to determine that both pilots had their respective NVG-HUD set to display Page 2. More on the specific information displayed on Page 2 is found at para 1.18.10;

b. The two IR searchlights were turned on. However, the data only records the on/off status and does not record any data as to the exact position/orientation of the IR searchlights. The CVR recording had no information about the position/orientation and/or the effectiveness of the IR searchlights;

c. At least one Flight Director cue was active (specific modes/axes unknown/not recorded on FDR) but not coupled (the aircraft was flown using the Core Mode DAFCS), in the last 13 minutes of the mission. Under this mode of operation, the Flight Director will display information on the MFD (cue) to guide the PF of the actions to take to maintain the desired conditions (e.g. heading, altitude, descent rate, etc...);

d. The Trim Roll Right Advisory was active for the final 30 seconds of flight. This condition did not impact the PF's ability to control the aircraft (There was no roll ILCA saturation in the final 26 seconds of flight - 1.6.15); and

e. No other warnings, cautions or advisories were found that could have contributed to the accident.

MISSION CARD

1.11.14 The aircraft is equipped with a mission card that is used by the crew to load various mission items such as flight plans, radio presets, navigational presets, and landing zone information to be displayed on the MFD. The mission card was recovered from the wreckage, revealing the following information:

a. The planned speed and altitude to confined area T40 was 90 knots Groundspeed at 100 ft AGL; and

b. All four HUD declutter levels (1.18.8) were pre-programmed to display identical information on both pilots' HUD. The investigation could not determine if the information was loaded from the mission card to the aircraft[27].

1.12 WRECKAGE AND IMPACT INFORMATION

1.12.1 The aircraft impacted the water approximately 400 m from the shore of Wegner Point in Petawawa. The aircraft came to rest on the riverbed on its right-hand

[27] The aircraft remembers the last settings, so it may be possible the HUD pages were not as per the mission card.

side at a depth of approximately 25 m (Latitude: N45 57.2579 / Longitude: W077 18.1470). The aircraft was entirely submerged in the Ottawa River for 23 days.

1.12.2 The force of impact on the cockpit area caused extensive damage. The brunt of the impact crushed the cockpit inwards and upwards from left to right, with many structures being compressed towards the rear, including both pilot seats. The aircraft battery separated from the airframe on impact and was never found.

1.12.3 The right side fuel cell and pod shell located at Fuselage Station (FS) 275 to FS 440 (Figure 10) separated from the aircraft at impact (Photo 2). The right-side fuel cell and parts of the pod shell were found floating near the accident site. The left side fuel cell and pod shell remained attached to the aircraft.

1.12.4 The underside of the aircraft sustained significant damage from FS 95 to FS 360, with most of the exterior skin having been ripped off. All bulkhead frames from FS 360 forward were detached, fractured, and displaced rearward.

1.12.5 Multiple cabin floor panels separated from the aircraft structure in numerous areas from FS 120 to FS 420.

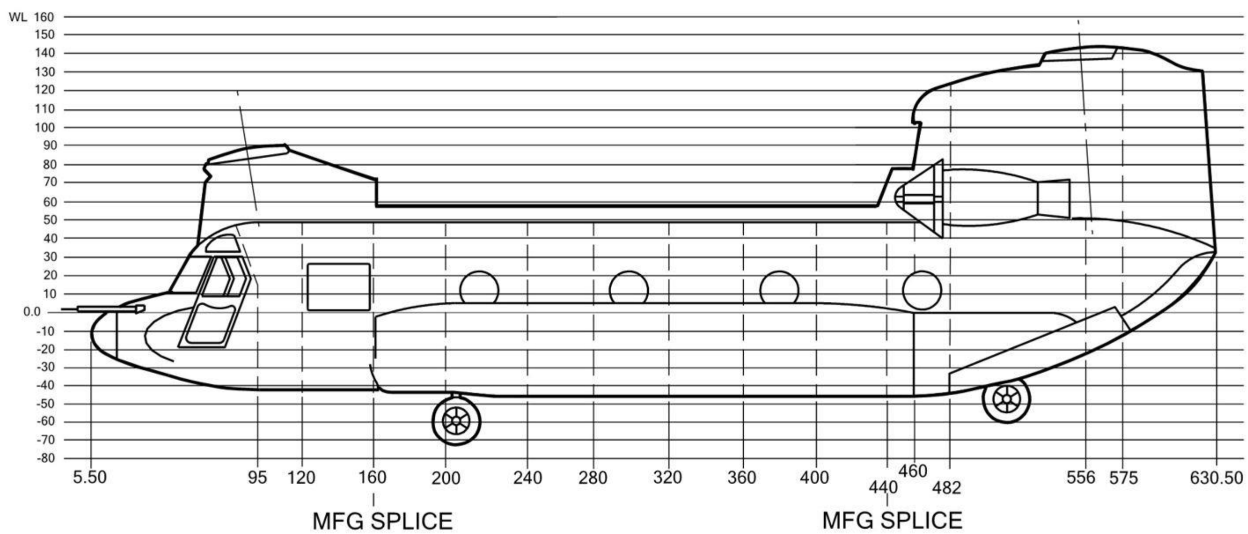

Figure 10 - CH147F Fuselage Stations and Waterlines

Photo 2 - Right side fuel cell (with POL absorbent material)

1.13 MEDICAL

1.13.1 Given that both FEs survived the accident while the pilots did not, the investigation assessed those factors including, but not limited to, medical factors that may have contributed to the pilots being unable to successfully egress the aircraft. There were multiple factors that, when combined, explained the fatal outcome:

- Both pilots were recovered still strapped into their respective seat with no indications of any attempt to unstrap or egress;
- Both pilots' Emergency Breathing System (EBS) bottles were still showing full (1.15.44);
- The impact forces were more than 60G (1.11.8); and
- The results of the post-mortem evaluation (autopsies).

1.13.2 In reviewing all medical and survivability factors, it was determined that one pilot sustained fatal injuries on impact while the other pilot was rendered unconscious, and as such, unable to egress the aircraft and subsequently drowned.

1.13.3 Toxicology testing did not reveal the presence of any substances hazardous to aviation.

SPATIAL DISORIENTATION

1.13.4 Orientation perception is a combination of visual, vestibular (semi-circular canals and otoliths[28]) and somatosensory[29] inputs. It is widely accepted in the aviation industry that aircrew relying mostly on otolith and somatosensory information/sensations

[28] The otolith organs are located in the human vestibular system and sense gravity and linear acceleration due to initiation of movement in a straight line.
[29] Somatosensory is relating to or denoting a sensation which can occur anywhere in the body, in contrast to one localized at a sense organ (such as sight, balance, or taste).

in the absence of adequate visual reference are at risk of experiencing spatial disorientation.

1.13.5 Type 1 – Unrecognized spatial disorientation[30] occurs when the pilot is completely unaware of a disorientation condition and continues to control the aircraft based on misperception of actual orientation[31].

1.13.6 Spatial disorientation is insidious. Around 33% of United States (US) civil aviation accidents from 1913 to 2011 can be attributed to spatial disorientation, however, these 33% of accidents account for almost 100% of the fatalities[32]. The US Navy reported that during fiscal years 2001 to 2005 spatial disorientation accounted for 35% of accidents, and 96% of fatalities[33].

1.13.7 Factors that may contribute to unrecognized spatial disorientation:

a. Reduced Field Of View (FOV) when using NVG. NVG are used to amplify illumination, however, one disadvantage to using them is a reduced FOV. Unimpeded horizontal human FOV ranges from 114 to 214 degrees. The use of NVG reduces that FOV to approximately 40 degrees. This reduced FOV creates an environment where the pilot needs to turn their head to see their peripheral surroundings. Spatial orientation is strongly linked to peripheral vision with an estimated 90% of visual effects on position changes perceived from peripheral vision[34]. Spatial orientation thus becomes more difficult to maintain under this reduced FOV while using NVG.

b. Lack of references and false horizon visual illusion. "A false visual reference illusion may cause a pilot to orient their aircraft in relation to a false horizon. Caused by flying over a banked cloud, night flying over featureless terrain with ground lights that are indistinguishable from a dark sky with stars, or night flying over a featureless terrain with a clearly defined pattern of ground lights and a dark, starless sky"[35].

c. Task saturation. As cognitive workload increases, the ability to maintain good situational awareness of the aircraft's location in space might be affected or reduced. Situational awareness is defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future." Task saturation often comes alongside channelized attention as the

[30] Type 2 (Recognized spatial disorientation) and Type 3 (Incapacitating spatial disorientation) were not deemed relevant to this investigation.
[31] Gibb, Gray and Scharff. 2010. Aviation Visual Perception: Research, misperception, and mishaps. 1st Edition. (Abingdon-on-Thames, Oxfordshire: Routledge).
[32] Gibb, Ercoline and Scharff. 2011. *Spatial Disorientation: Decades of Pilot Fatalities.* Aviation Space Environmental Medicine 2011; 82:717 - 24.
[33] Ostrander. 2006 *Physiological episodes and related mishaps FY2001-2005: A descriptive analysis.* USN Aeromedical Programs Naval Safety Center.
[34] Reinhart, R.O. 2008. Orientation. Chap 8. In *Basic Flight Physiology*. 3rd Ed. (NY: McGraw-Hill).
[35] Spatial D (faa.gov) Spatial Disorientation: Visual illusions pilot safety brochure.

crew, when task saturated, tend to focus on specific tasks to the exclusion of other inputs[36].

d. Mental and physical state. From a mental and physical aspect, factors that could influence susceptibility to unrecognized spatial disorientation would include: fatigue, emotion, stress, drugs, poor health, medication, and attitude (e.g. motivation, nervousness, and complacency)[37].

1.13.8 The most serious outcome of spatial disorientation is Controlled Flight Into Terrain (CFIT). CFIT occurs when an airworthy aircraft under the complete control of the pilot is inadvertently flown into terrain, water, or an obstacle. The pilots are generally unaware of the danger until it is too late.

AEROMEDICAL TRAINING (AMT)

1.13.9 AMT is an educational program that combines academic and hands-on teaching and is designed to educate and familiarize its participants with aviation topics of concern related to human physiological limitations leading to spatial disorientation, hypoxia, thermal stress and issues related to altitude, vibration, high G forces and some night vision training. The standard for such training is designed to be interoperable with Five Eyes Air Force Interoperability Council (AFIC) and North Atlantic Treaty Organization (NATO) allies.

1.13.10 Spatial Disorientation instruction is limited to in-class teaching during AMT and reinforced with practical demonstration using a Bárány chair[38].

ABILITY TO DETECT ACCELERATION

1.13.11 The investigation looked at the threshold for human detection of acceleration with the intent to determine if the acceleration forces preceding the crash could have influenced the pilots' situational awareness. The human vestibular system, particularly the otolith organs, determine the ability to detect change in translational movements. Its main limitation is an inability to sense movement at a steady velocity but rather detects changes in velocity, otherwise known as acceleration. Owing to fewer sensory cells and the ever-present force of gravity, we are far less effective at sensing vertical acceleration as compared to horizontal. Based on several studies, the accepted

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[36] Gawron V. 2004, Psychological Factors. Chapter 4 In F.H. Previc and W.R. Ercoline (Eds) Spatial Disorientation in Aviation. 1st Ed. (Reston, Virginia: American Institute of Aeronautics and Astronautics Inc.). 145-195.
[37] Ibid.
[38] A physiological training device designed to demonstrate Vestibular illusions due to angular accelerations predominantly in a single axis and to demonstrate by simulation some of the adverse effects of spatial disorientation.

threshold value for detecting acceleration is 0.005 – 0.01G in horizontal directions and 0.01 to 0.1G in the vertical direction[39].

1.13.12 A factor not specifically highlighted in the literature that quoted these thresholds is the effect of whole-body vibration on these specific thresholds. This is worth considering given the presence of vibration forces in rotary-wing operations and the known impact these have on several physiological processes. Although data is unavailable to determine an objective value of the effect of the CH147F's vibration profile on otolith threshold function, the encyclopedia of Occupational Health and Safety cites related research that indicates whole-body vibration imposes at temporary threshold shift (i.e. decrease in sensitivity or higher threshold) on the vestibular organs.

HUMAN RESPONSE TIME

1.13.13 The investigation considered human response time, more specifically the time it would take for a pilot to respond to the RADALT low altitude audio warnings. The terms *reaction time* and *response time* are often used interchangeably, but there is a distinction between them. Reaction time is the elapsed time from stimulus perception at the neurological level to motor or muscle initiation (i.e. to respond to the warning being heard), while response time is the time required to respond to a stimulus (i.e. reaction time) with an action (i.e. action time) or essentially the time from brain signal to the completion of a task (i.e. hit a button or move the flight controls). In simple terms:

RESPONSE TIME = REACTION TIME + ACTION TIME.

1.13.14 The Directorate of Technical Airworthiness and Engineering Support (DTAES) Human Factors section was asked to conduct a literature review to better understand human response time. Their review indicated that the Reaction Time for a commonly accepted stimulus can take around 2.5 seconds. This Reaction Time value is considered a best-case scenario, which could be extended by several factors, including stimulus-response alternatives (i.e. the number of response options available to a stimulus response), stimulus-response compatibility (i.e. if a "natural" or complex response is required), practice, stress level, recovery from a missed response (e.g. incorrect anticipation), etc. A simple Action Time would take between 0.2 and 0.33 of a second; and may increase significantly if the action requires multiple movements.

1.13.15 In the case of *Hammer 31*, the pilot action being assessed (simultaneous movement of thrust level and cyclic stick) is not considered complex, nor the simplest. Given that action, the best-case scenario of 2.5 seconds was considered unlikely. The investigation used a Response Time of 3.0 seconds to account for a Reaction Time and Action Time of 2.7 and 0.3 seconds respectively.

[39] Cheung, Bob. (2004). Nonvisual Spatial Orientation Mechanisms. Chapter 2. In F.H. Previc and W.R. Ercoline (Eds.) Spatial Disorientation in Aviation. 1st Ed. (Reston, VA: American Institute of Aeronautics and Astronautics). 37-94.

1.14 FIRE, EXPLOSIVES DEVICES, AND MUNITIONS

1.14.1 The CH147F has two engine fire extinguishing bottles which contain Halon under pressure. Explosive squibs that are electrically actuated are used to dispense the retardant into the selected engine.

1.14.2 Both left and right fuel tanks are equipped with a fuel jettison system. Explosive squibs that are electrically actuated are used to allow a pressurized charge of nitrogen to extend the two jettison tubes out from the tanks to achieve a safe distance away from the airframe for fuel to be jettisoned.

1.14.3 All explosive devices were recovered and destroyed; and the Halon was recovered. There was no pre-crash or post-crash fire.

1.15 SURVIVAL ASPECTS

EMERGENCY LOCATOR TRANSMITTER

1.15.1 The Emergency Locator Transmitter (ELT) was immediately activated upon water impact. The ELT could be heard on the CVR of Chinook CH147309 (*Hammer 32*), the other aircraft that was flying that night.

1.15.2 None of the crew members were fitted with Personal Locator Beacons as is common practice in other communities.

EMERGENCY RESPONSE

<u>Emergency Response Plans</u>

1.15.3 There are two Emergency Response Plans (ERP) that the investigation examined: the 4 Canadian Division Support Base (CDSB) Petawawa - Garrison ERP, and the 450 THS Crash Response Plan (CRP). The 4 CDSB Petawawa Garrison ERP was dated Apr 18. The 450 THS CRP is promulgated as Squadron Standing Order 311 and was dated 1 Jul 19. The Airworthiness Investigation Manual (AIM) states that the ERP should be reviewed and exercised periodically[40].

1.15.4 There was also another separate contingency plan that pertained to the accident response: the 2 Canadian Mechanized Brigade Group (CMBG) Force Generation Order – Immediate Response Unit (IRU) 2022-2023[41]. This order was signed 5 Apr 22. The intent of the 2 CMBG IRU is to generate a task-tailored and scalable force to meet various Canadian Armed Forces (CAF) commitments, both domestically and internationally, and to respond to emergency situations. The 2 CMBG IRU, being a contingency plan, is generic in nature and is not designed specifically to deal with aircraft accidents. The Commander 2 CMBG did activate the IRU, the Royal

[40] A-GA-135-003/AG-001, Airworthiness Investigation Manual, Chapter 6, Para 8, 30 Jul 24.
[41] 4500-1 (G5-2) 2 CMBG Force Generation Order – Immediate Response Unit (IRU) 2022-2023, dated 5 Apr 22.

Canadian Dragoons at the time of the accident and made it available to the Commander 4 CDSB to assist in their response efforts to the *Hammer 31* accident.

1.15.5 Closer examination of the 4 CDSB Garrison ERP revealed that the telephone number listed to report an aircraft accident was incorrect. The number to report an aircraft accident to the Directorate Flight Safety (DFS) is 1-888-927-6337.

1.15.6 1 Wing Headquarter (HQ), the Wing that oversees 450 THS, located in Kingston, ON was found not to have a wing level ERP.

Search & Rescue (SAR)

1.15.7 The first notification of an accident to the base emergency services was received at 0010 L via a "one-bell" on the aircraft emergency alarm system. The emergency alarm system was activated by the MFAU duty advisor. The fire department at Garrison Petawawa is operated from two fire stations: Station-1 is located close to the Garrison main entrance, and Station-2 is located close to the airfield. For this report, Station-1 will be referred as the Garrison Fire Hall, and Station-2 will be referred as the Crash Fire Hall (Figure 11). The Garrison Fire Hall has a Public Announcement system (PA system), but broadcasts made are not retransmitted automatically to the Crash Fire Hall. Someone from the Garisson Fire Hall is required to retransmit the messages by calling the Crash Fire Hall. The key timings for the emergency response that are relevant to the investigation are depicted in Table 3.

Time (local)	Event
00:08	Accident
00:10	One-bell alarm activated
00:18	Crash Fire Hall first responders on-scene (Wegner Point)
00:38	First ambulance arrives on scene
00:40	First responders' Zodiac boat arrives on scene
00:48	Two survivors recovered from the water

Table 3: Timing of key emergency response events

1.15.8 The SAR operation was divided into two distinct efforts: one from the beach at Wegner Point nearest to the accident site and the other from a Zodiac watercraft (Photo 3 and Table 4). The Zodiac boat had to be launched from the Jubilee Marina (Figure 11), which is located approximately five kilometres away from its storage location close to the Garisson Fire Hall.

1.15.9 Early communication with the first responders indicated an accident "in the water, East of the tower". This was not specific enough for the first responders to know exactly where to go to find the accident site; however, the on-scene aircraft (*Hammer 32*), marking the floating debris field with its external lights, provided a terminal reference. With this information, the first responders were able to make their way to the beach nearest the accident site within 10 minutes of the one-bell alarm.

1.15.10 Once on the beach, the first responders were able to hear survivors in the water calling for help and stating they were not able to swim much longer. They also reported their legs were starting to cramp up, making it even more difficult to swim. To help the survivors know in which direction to swim the first responders turned all the emergency vehicles headlights on and pointed them in the general direction of where they were hearing the calls for help.

1.15.11 Knowing that time was of the essence, and still waiting for the Zodiac to arrive, the first responders at Wegner Point entered the water on foot to make their way closer to the survivors. They were forced to turn around as the water was getting too deep too quickly and they were still too far from the survivors. One first responder remembered noticing four canoes that were lying on the ground as they were driving to Wegner Point. The canoes were located approximately 100 m away from the shore. A few first responders went back and brought two canoes to the shore and immediately boarded them to make their way to the survivors. The first survivor to be rescued by a canoe was the Cabin Door FE. The Ramp FE was rescued shortly after by the Zodiac crew who had, by then, made it to the accident site.

Photo 3 - Zodiac watercraft used by the first responders

Zodiac overall length:	19 ft
Zodiac overall width:	7 ft
Zodiac working space:	13 ft x 3.5 ft
Zodiac carrying capacity (weight):	1485 lbs
Zodiac carrying capacity (passengers):	9

Table 4: Zodiac watercraft specifications

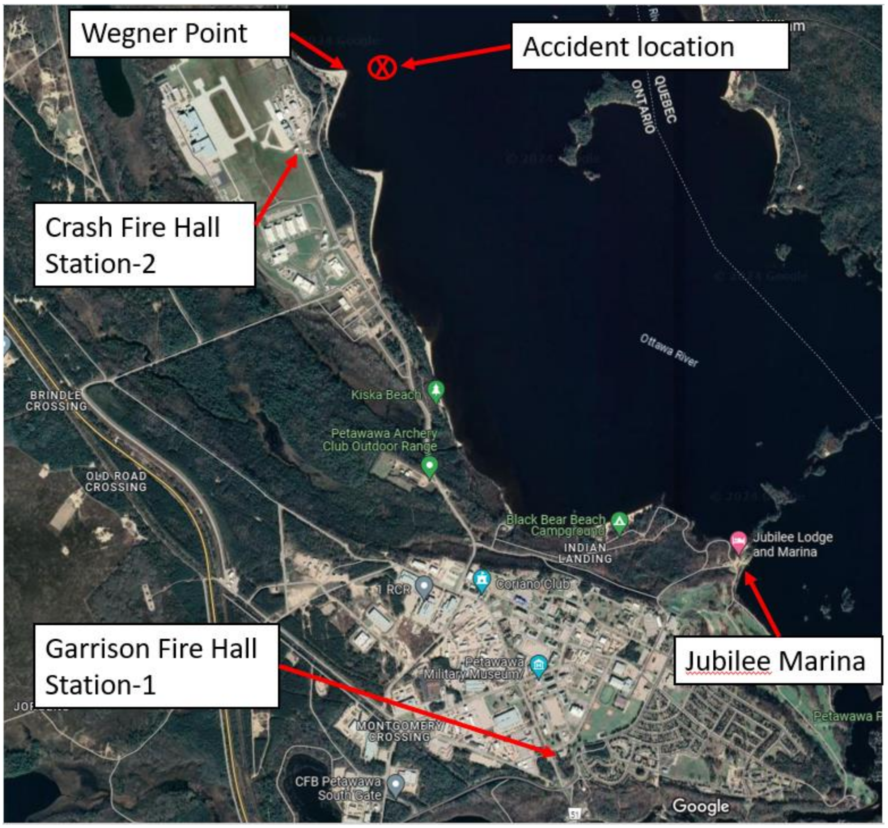

Figure 11 - Satellite image of Accident location (Google Maps)

<u>On-Scene Controller of Emergency Response (OSCER)</u>

1.15.12 The primary role of the On-Scene Controller of Emergency Response (OSCER) is to control the multiple organizations and assets that are required to attend an emergency. In responding to this accident there were two individuals assigned as OSCER to ensure 24/7 coverage of the accident site, one Captain and one Warrant Officer (alternating day and night).

1.15.13 Search and recovery efforts were made more complex by the accident occurring on the water, requiring multiple organizations and assets to respond. To add to the complexities these organizations and assets were drawn from multiple elements; the RCAF, the Canadian Army (CA), and civilian agencies. The complexities of the site required that a temporary camp be set up on the beach at Wegner Point (Figure 11) which necessitated a great deal of logistical support to provide for workspaces, personnel for the recovery operation and control of the site, shelter from the elements, food & water, and portable toilets.

1.15.14 In many instances OSCER made requests for support which took many hours before being actioned or receiving an update as to the progress of their request. Two examples of such situations were the request for water and portable toilets, which were only provided nearly 18 hrs after the accident. Conversely, resources were also provided to OSCER without them making any specific request for them or knowing that they would now have to manage these additional resources. For example, personnel from the 2 CMBG IRU were dispatched to Wegner Point unbeknownst to OSCER and would now report to them.

1.15.15 OSCER typically has a duty vehicle that is on permanent standby to respond in case of an accident. This vehicle contains most of the required equipment for OSCER to carry out their duties. Those assets include crash maps and radios. At the time of the accident the OSCER duty vehicle was at the dealership for repairs and as such was not available the day of the accident. There was no back-up plan in place to support OSCER while the duty vehicle was away from the base.

1.15.16 Communications between Wegner Point and the Base were difficult. OSCER did not have a radio due to the lack of duty vehicle and cell reception was limited by the geography of the area. This limited reception resulted in difficulties making voice calls, however, messages could be sent via SMS or messenger apps. In some cases, due to this lack of voice communication, personnel involved in the response over the first 24 hrs were using their personal Facebook Messenger to communicate.

ESCAPE AND SURVIVABILITY

Escape

1.15.17 The pilots did not egress from the aircraft.

1.15.18 Before impact, the Cabin Door FE was located near the cabin door, while the Ramp FE was at their station near the ramp (Figure 12). The ramp was closed with the tongue[42] open (retracted). Neither FE was strapped into a cabin seat; they were secured only by their tether, commonly referred to as a “monkey tail”, which was attached to a cabin floor strong point near their crew station. On impact with the water the two FEs were thrown around in the cabin area which, combined with the darkness, resulted in them being disoriented. Eventually, and with the use of their EBS, the two FEs were able to manually disconnect their monkey tails from their Eagle Vest. No lights were visible, which made it difficult to locate the nearest emergency exit, ultimately delaying egress. They were eventually able to locate the opened escape hatch (Door Gunner Window) and egress the sinking aircraft.

[42] To close the rear section of the Chinook, both the ramp (hinged on the floor) and the tongue (hinged on the ceiling) need to be closed.

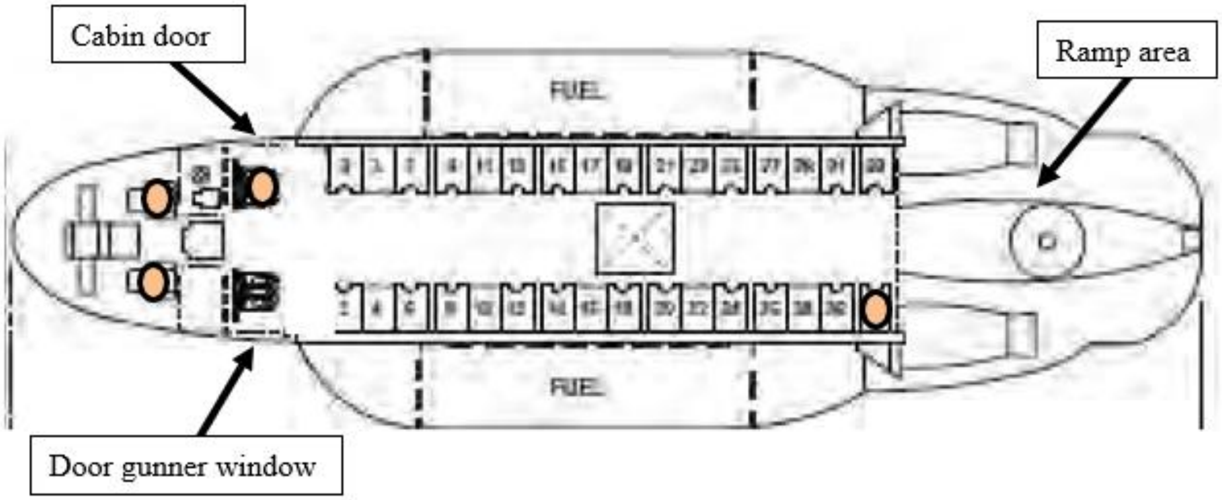

Figure 12 - Location of occupants (Circles) and opened emergency exits, prior to impact

1.15.19 Because neither FE could swim to shore, and because their Damage Tolerant Life Preserver (DTLP) had been removed from their Eagle Vest, they both discarded their Eagle Vest and helmet and used aircraft debris for flotation until they were rescued by first responders (1.15.11).

Aircraft Emergency Exits and Emergency Lights

1.15.20 The CH147F rear cabin has three emergency exits: the rear ramp, the cabin door (located on the right side of the aircraft), and the escape hatch or Door Gunner Window (located on the left side of the aircraft, opposite the cabin door). Each emergency exit is equipped with one emergency light located overhead the exit. The emergency lights are designed to illuminate whenever a loss of power on the aircraft essential bus occurs or during a hard landing above 3 to 4G is sensed by an inertia switch. It was reported that emergency exit lighting was not visible post-impact, resulting in both FEs having to escape the cabin in total darkness.

1.15.21 The Quality Engineering Test Establishment (QETE) conducted extensive testing of the emergency exit lighting system. The details of these testing efforts are included in section 1.16 of this report (1.16.1).

Risk of Hypothermia

1.15.22 The water temperature on 21 and 22 Jun 23 was recorded at 16.6ºC. It can be assumed that the temperature would have been very similar on 20 Jun 23, the day of the accident. The first responders' records indicate that the two FEs spent between 30 and 40 min in the water before being rescued. Both FEs were shivering and exhausted from treading water in their clothing.

1.15.23 The investigation assessed the risk of hypothermia using the Defence Research and Development Canada Cold Exposure Survival Model (CESM)[43]. The CESM includes many factors to determine an individual's functional time and survival time. Functional time is the estimated elapsed time during which an individual's body core temperature decreases from 37°C to 34°C. During functional time, individuals maintain an acceptable cognitive and physical level of performance to keep themselves alive. Survival time is defined as the estimated time for the core temperature to reach 28°C.

1.15.24 The CESM results indicated that the worst-case scenario would yield a functional time of 4.88 hrs and a survival time of 8 hrs. From these results, the investigation concluded that hypothermia was not a survival risk.

AVIATION LIFE SUPPORT EQUIPMENT (ALSE)

1.15.25 The crew of *Hammer 31* were wearing the following ALSE gear:

a. HGU-56/P-CF Aircrew Helmet;

b. CIACS6 Gen II Tactical Aircrew Survival Vest System (Tac ASVS);

c. Integrated Life Preserver/Survival Vest (LP/SV);

d. EBS SEA LV-2; and

e. FE crew harness tether (monkey tail).

1.15.26 More specifically, the SP and the two FEs were wearing the CIACS6 Tac ASVS while the IP was wearing the LP/SV instead due to medical limitations/restrictions. All crew members' vests were equipped with an EBS. All crew members were wearing the HGU-56/P-CF helmet. A review of the ALSE maintenance records revealed the latest periodic inspections to be up to date, and the latest fitting were completed as follows (Table 5):

Description	Serial #	Date the Last Fitting was Completed
Pilot		
Survival Vest	LP/SV 003022	6 Mar 20
Helmet	HGU-56/P-CF 003077	27 May 19
Pilot		
Survival Vest	Eagle Vest 20210018	19 May 22
Helmet	HGU-56/P-CF 170430	08 Nov 19

[43] Tikuisis, P. 2002, Cold Exposure Survival Model. Undersea and Hyperbaric Medical Society Proceedings. 149-154.

Description	Serial #	Date the Last Fitting was Completed
FE		
Survival Vest	Eagle Vest 20210002	27 Apr 22
Helmet	HGU-56/P-CF 150059	15 Apr 21
FE		
Survival Vest	Eagle Vest 0012	06 Oct 20
Helmet	HGU-56/P-CF 140254	20 Jul 22

Table 5: ALSE Fitting Dates

1.15.27 The ALSE worn by the crew was examined to assess its effectiveness in protecting the crew members as well as allowing for a safe and expedient emergency egress from the aircraft.

General Observations

1.15.28 The inspection of the ALSE, both from the crew of *Hammer 31* and from other aircrew at the unit, revealed multiple anomalies which are not isolated circumstances. A few examples of these anomalies include:

- Undocumented maintenance;
- Maintenance carried out but not in accordance with the technical manuals;
- Equipment being installed/adjusted incorrectly;
- Improper care/maintenance of the equipment; and
- Improper/incomplete sealing of pouches, containing vest survival items, allowing for water ingress causing increased weight.

1.15.29 Only the anomalies that are germane to the accident and this investigation will be covered in the following sections, with the others being referred to the technical authority separately.

HGU-56/P-CF Aircrew Helmet

1.15.30 All four aircrew helmets were recovered and inspected shortly after the accident. The two FEs had discarded their helmets after they broke water surface, one of the pilot's helmet was found floating, and the other pilot's helmet was found still securely attached. They all showed signs of wear, improper maintenance, and previous Energy Absorbing Liner (EAL)[44] compression.

[44] The Energy Absorbing Liner (EAL) is a layer of dense Styrofoam inside the helmet shell that provides shock/impact protection to the user.

1.15.31 A visual inspection of the pilot's helmet found floating revealed damage to the helmet shell with no corresponding damage identified on the EAL. This evidence suggests the helmet was not in a static and secure position at the time the damage was inflicted on the shell surface.

1.15.32 A visual inspection of the pilot's helmet that was still securely attached revealed damage which is consistent with the impact sustained in the accident. The main anomalies noted with this helmet are undocumented maintenance and that the chin-strap was not routed as per the technical orders.

1.15.33 A visual inspection of the FE's helmets did not reveal any significant damage caused by the impact and indicated that the integrity of the helmet shell remained intact.

1.15.34 At the time of the accident, 450 THS was operating under a Specific Purpose Flight Permit that allowed for the use of the Zeta III liner inside the HGU-56/P-CF helmet[45]. A closer examination revealed that one of the FE's helmets had the wrong size liner installed inside the shell. The helmet size was an extra-large and the Zeta III[46] liner was a large. A review of the maintenance records showed that the installation of the Zeta III liner was not documented.

CIACS6 Gen II Tac ASVS

1.15.35 The CIACS6 Gen II Tac ASVS, commonly referred to as the "Eagle Vest", is comprised of a combat integrated armour carrier, a fully integrated and removeable compact DTLP, and a harness kit in two configurations: pilot and FE. The FE configuration includes a Crewman Releasable Restraint (CRR) system.

1.15.36 The DTLP is activated manually and provides floatation while maintaining the end user in a face up position. The DTLP can be removed from the Eagle Vest by the end user. The order that governs life preservers and survival vests is the 1 Canadian Air Division (1 CAD) Flight Operations Manual (FOM)[47] (Annex H). The FOM states that "Personal Survival Vests or crewmember Life Preserver/Survival Vests (LP/SV) shall be worn as dictated by mission requirements". The SP and the two FEs were all wearing their Eagle Vest with their DTLP removed. This was common practice due to binding and comfort issues.

Integrated LP/SV

1.15.37 The LP/SV consists of a Life Preserver (LP) assembly fully integrated with the survival vest and is commonly referred to as "the old style" LP/SV. Like the DTLP, the LP is activated manually and provides floatation while maintaining the user in a face up position. However, unlike the DTLP, the LP portion of the vest cannot be removed from the LP/SV by the user. Removing the LP is possible but is a maintenance task that must

[45] J FT6-3 2021-001 Rev. 1.
[46] The Zeta III is available in three different thicknesses (size) for each helmet size and the thickness is determined by the layers required in the thermoplastic liner.
[47] FOM 4.2.2.9 - Life-Jackets/Emergency Breathing Equipment/Survival Vests.

be carried out by an ALSE technician. Only the IP was wearing the LP/SV, and the LP was installed.

<u>Binding Between Aircrew Helmet and Life Preserver</u>

1.15.38 On 9 Jun 20 there was a Flight Safety Hazard Report (HAZREP) generated by 413 Sqn in 14 Wing Greenwood[48] to report issues with the HGU-56/P-CF helmet binding on the life preserver portion of the LP/SV. The HAZREP triggered a Risk Alert Notice on 26 Jun 20 and an Airworthiness Risk Alert was accepted on 2 Jul 20. A Record of Airworthiness Risk Management (RARM) was issued on 7 Jul 20[49], where the risk was assessed at a Risk Index of LOW, resulting from a probability assessed as frequent and a severity of minor.

1.15.39 At the time of the accident there was no RARM to document any risks associated with binding between the HGU-56/P-CF helmet and the DTLP on the Eagle Vest. On 14 Nov 23, the Airworthiness Investigative Authority (AIA) issued an immediate preventive measure to verify if the binding between the vest and the DTLP could be causing excessive limitation in movement which could impact safe operation. This immediate preventive measure triggered a RARM that was issued on 22 Nov 23[50]. The risk was assessed at a Risk Index of MEDIUM to EXTREMELY HIGH, depending on the risk scenario (three scenarios). On 21 Nov 23, while the staff work was being done to issue the RARM, 1 Wing HQ issued an Ops Restriction to immediately cease flying operations with the DTLP attached to the Eagle Vest, bringing the mitigated risk level to Acceptable Level Of Safety (ALOS).

1.15.40 Before the Eagle Vest had entered service, 1 CAD tasked the Land Aviation Test and Evaluation Flight (LATEF) to complete an Operational Test and Evaluation (OT&E) to ensure its operational suitability with the CH146 Griffon. The LATEF OT&E report[51] stated that one pilot test subject experienced head restriction when clearing turns and noted that the HGU-56/P-CF helmet was rubbing on the Eagle Vest. This resulted in further limited head movement and increased fatigue. The report also found that the other pilot test subject did not experience this limitation in head movement. The report concluded that the Eagle Vest allows aircrew to execute most of their regular duties and emergency procedures, however, minor compensations are required. The LATEF OT&E report did not cover the CH147F as the report pre-dated the entry into service of that aircraft.

1.15.41 The investigation found two separate Statement of Capability Deficiency (SOCD) reports that raised the issue of binding between aircrew helmets and the Eagle Vest. One was submitted by 427 SOAS in Nov 20, and another by 450 THS, signed but undated. The investigation reviewed the yearly 1 CAD Prioritized SOCD list for the years 2020 to 2024 and the CH147F fleet Annual Airworthiness Review reports for the

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[48] FSIMS #186143, Helmet and LP/SV Binding, 413 Sqn, 9 Jun 20.
[49] RARM ALSE-2020-001, HGU-56P-CF Helmet and LP/SV Binding, 7 Jul 20.
[50] RARM ALSE-2023-004, Damage Tolerant Life Preserver (DTLP) on Eagle Vest Interference with Aircrew Helmets.
[51] LATEF 2010-009 – Tactical Aviation Survival Vest System –13 Apr 11.

same period, and neither SOCD was ever mentioned on any of these lists or reports. This indicates a breakdown in communication, but the investigation could not identify the exact source of the issue.

EBS SEA LV-2

1.15.42 The EBS SEA LV-2 is a compact, lightweight breathing apparatus intended for emergency use by helicopter aircrew in the event of a crash landing in water (ditching). The EBS is carried in a special pocket and the mouthpiece is located inside a cover which is secured to the Eagle Vest or LP/SV. This EBS (2.5 cubic-feet) provides 24 breaths of air at 1.5 L per breath.

1.15.43 The FOM mandates that EBS shall be worn for overwater flight[52] below safe single engine speed (1.6.17) and extended overwater operations[53] of 10 minutes or more from shore. The flight of *Hammer 31* did not meet any of those two conditions, hence the crewmembers were not mandated to wear their EBS cylinders. The FOM also states that rotary-wing aircraft crewmember's LP/SV should be equipped with an EBS as dictated by mission requirements[54]. The 450 THS Flying Orders state that EBS cylinders may be removed except for those conditions identified in the FOM. In this instance, all crew members were fitted with EBS.

1.15.44 All EBS cylinders were recovered after the accident. Upon inspection it was noted that both pilot EBS cylinders were still full, the Cabin Door FE EBS was half-full, and the Ramp FE EBS was three-quarters full. Both FEs used their EBS during their egress from the aircraft.

1.15.45 On 26 Jun 23, after the accident of *Hammer 31*, 450 THS issued three Aircrew Information Files (AIF) to provide directives and restrictions related to safe operation (Annex I). AIF 23-18 was specifically targeted at the wearing of EBS and LPs for over water ops. It stated that all aircrew shall wear EBS and LPs on all flights overflying any bodies of water. The AIF is more restrictive than the FOM, meaning that the new unit directive is safer than the FOM order.

FE Crew Harness Tether & Crewman Releasable Restraint (CRR)

1.15.46 The FE configuration of the Eagle Vest includes a crew harness tether, or "monkey tail", which is an adjustable tether that incorporates a safety-gate snap hook on each end. One safety-gate snap hook is attached to the CRR system on the back of the harness, and the other is attached to a strong point on the aircraft. The CRR is a three-ring release system that allows for emergency release of the monkey tail from the Eagle Vest, even when the monkey tail is under tension, allowing for unrestrained egress from the aircraft.

[52] FOM 3.6.2.24 RUET/EBS Training.
[53] FOM 2.4.9.2 CH147F Extended Overwater Operations.
[54] FOM 4.2.2.9 Life-Jackets/Emergency Breathing Equipment/Survival Vests.

1.15.47 Operating the CRR system is a two-stage process. The first stage involves pulling the beaded ripcord handle outward, then upward to release the snap fastener. The second stage involves pulling the ripcord beaded handle in a downward motion to full arms length. These two stages activate and release the three-ring system in the back of the vest. An attempt was made by one of the FEs to pull the beaded ripcord handle, the snap fastener did not release, indicating stage 1 had not been successful. Eventually, the FE was able to manually disconnect their monkey tail.

1.15.48 The leg straps are adjusted during the user fitting process and tacked (stitched) by the ALSE section. Once tacked, the straps cannot be adjusted by the end user. This means that the straps need re-adjusting with season changes (i.e. changing flight clothing from winter gear to summer gear) (Table 5).

EMERGENCY ESCAPE TRAINING

Annual Emergency Egress Training

1.15.49 The RCAF FOM mandates that emergency aircraft egress training be conducted annually[55]. The FOM order does not detail how this annual training is to be conducted. More specifically, it does not dictate the use of the CRR system incorporated into the FE configuration of the Eagle Vest.

1.15.50 Pulling the CRR release handle would require an ALSE technician to rig the system after each pull. This would cause additional work for the ALSE shop technicians and require additional annual emergency egress training time. Some units have used spare Eagle Vests equipped with a CRR system during annual egress training which permitted crewmembers to exercise the CRR system. This approach limited the amount of additional work for the ALSE shop technicians.

Rotary-Wing Underwater Escape Training (RUET)

1.15.51 RUET/EBS training has been recognized to have saved the lives of aircrew in several accidents involving helicopter ditching. As a result of this training, operators are more cognizant of the challenges they face in extracting themselves from a submerged aircraft.[56]

1.15.52 As mandated in the RCAF FOM, RUET/EBS training for Tactical Aviation shall be completed within 12 months of Operational Training Unit (OTU) or OTF[57] completion. RUET/EBS qualification validity periods are based on the mission profile and aircraft type being flown as detailed in Table 6.

[55] RCAF FOM, 3.6.2.25 - Aircrew Currency Requirements.
[56] 1 CAD Order, 5-306 – Rotary-Wing Underwater Escape Training/Emergency Breathing Systems Training, 21 Mar 16.
[57] RCAF FOM, 3.6.2.25 - Aircrew Currency Requirements.

Fleet	Validity period	RUET/EBS Training Requirements
Tactical Aviation CH146 and CH147F	Between 5-10 years	Tactical Aviation aircrew shall undergo 1 CAD HQ contracted RUET/EBS training once every ten years but no more frequently than once every five years. Pilots new to 1 Wing shall complete RUET within one year of being awarded their flying category. Those who are not RUET qualified within this one-year period are not authorized to conduct overwater flight.
Special Operations Aviation CH146	5 years	Not authorized for flight below safe single engine speed beyond autorotative distance from land until training completed/renewed.
CH149	2 years	Shall complete RUET/EBS training prior to conducting SAR conversion training.
CH148	2 years	Egress and ditching drills shall be conducted Annually. Wet dinghy drills shall be conducted annually in a swimming pool or other suitable body of water and shall include survival swimming and instruction in the use of survival equipment.

Table 6: RUET/EBS qualification validity periods

1.16 TEST AND RESEARCH ACTIVITIES

TESTING OF EMERGENCY EXIT LIGHTING SYSTEM

1.16.1 The following information is the result of the extensive testing of the aircraft emergency exit lighting system QETE conducted in their laboratories.

1.16.2 The emergency exit lighting system includes three exit lights, an inertia switch, and an Interior Lighting (INTR LTG) panel. Each emergency exit light is removable from its base when the handle is operated. The INTR LTG panel, located in the cockpit overhead area, includes a three-position Emergency Exit (EMER EXIT) switch: TEST, DISARM, and ARM positions.

1.16.3 Power to operate the emergency exit lights is supplied by two internal 1.25 volt nickel-cadmium batteries. When the EMER EXIT switch is placed in the ARM position, the emergency exit lights remain off, the batteries charge, and the lighting circuit monitors electrical failures and hard landings. When the EMER EXIT switch is placed in the DISARM position, the system is inoperative. The EMER EXIT switch must set to DISARM when the aircraft is not operating (electrical power removed), otherwise the exit lights will illuminate and eventually discharge their internal batteries. The TEST position is used to check the operation of the exit lights when the aircraft is operating.

1.16.4 Components from the aircraft emergency exit lighting system were removed for examination when the aircraft had been recovered, after being submerged for approximately three weeks. The EMER EXIT switch on the INTR LTG panel was discovered in the DISARM position when the aircraft was recovered. The inertia switch assembly, which is not hermetically sealed, was not visibly damaged but had filled with water. It would no longer function during laboratory testing due to internal corrosion. Inertia switch assemblies do not have a periodic maintenance inspection cycle. The serviceability of the inertia switch assembly immediately prior to impact could not be determined based on post-accident condition.

1.16.5 All three emergency lights recovered were filled with water. The lights are hermetically sealed but were unlikely capable of resisting water ingress at a submerged depth of more than 25 m for several weeks. Two emergency lights exhibited possible pre-existing cracking at one or more housing fastener inserts, and as a result, a hermetic seal could not be achieved on those emergency lights post-accident. The nickel-cadmium batteries within the lights measured at or near zero volts. The batteries were shocked and reconditioned to recover approximately half of their nominal charge capacity. All three lights were reassembled with the original batteries and were found functional, producing a bright illumination for over 20 minutes (two of them while submerged under 10 inches of water).

1.16.6 For comparative testing a new emergency exit light and a set of new spare batteries were drawn from supply. After laboratory charging the new emergency exit light operated normally after being submerged in 10 inches of water for more than 35 minutes. The new spare batteries had to be reconditioned several times and attained only half of their nominal charge capacity. During first line verification of emergency exit lighting serviceability the lights are operated on internal batteries only momentarily, and therefore it is not clear how long (or at what illumination level) emergency lights would operate on internal batteries if the battery capacity has degraded substantially in service. Periodic verification of battery charge capacity, including verification of new batteries drawn from supply, and battery maintenance may be necessary to ensure maximum charge capacity is available from emergency lighting batteries.

1.16.7 When the fleet was initially introduced into the RCAF, QETE was tasked to measure the illuminance of the emergency exit lighting for the CH147F helicopter. The report concluded that “Based on the measurements of the emergency exit lighting taken on board the aircraft, the emergency exit lighting of the Chinook does not meet the minimum illuminance requirement of an average of 0.05 foot-candle illumination after a time of 10 minutes in the cabin or 0.05 foot-candle at the emergency exits” [58]. These QETE findings were considered when the CH147F fleet was assessed under the Occupant Safety Policy (OSP)[59]. The CH147F OSP - opportunities selection report[60], from Sep 19, recommends that the existing OEM modification for Helicopter Emergency

[58] QETE Project Report A022513, Photometric evaluation of emergency exit lighting of the Chinook helicopter (CH147F), 15 Jan 14.
[59]The OSP, launched in 2015, states: “All DND aircraft shall be equipped to optimize the safety and survivability of the occupants, while safeguarding operational capability and minimizing implementation costs”. The policy represents a safety improvement initiative that increases the probability of crew and passenger survival in the context of a survivable crash.
[60] RDIMS 1872593v2I, CH147F OSP, opportunities selection report, 27 Sep 19.

Egress Lighting System (HEELS) be implemented on the CH147F fleet. The project/modification has remained unfunded since 2019.

MAG BRAKE SWITCH ACTIVATION IN FLIGHT SIMULATOR AND ON FLEET FDR DATA.

1.16.8 QETE was tasked to conduct several investigative activities related to MAG BRAKE switch activations. The FDR data showed that during the last 16 seconds of the accident flight the MAG BRAKE switch was activated in rapid succession, accompanied by a slow gradual and constant lowering of the thrust control lever. The components associated with the MAG BRAKE were recovered and brought to the QETE Failure and Accident Investigation laboratory for further analysis. The intent of QETE's investigative tasks was to answer the following questions:

a. If activation rates of 2 activations per second were achievable;

b. If high activation rates were common across aircrew and/or aircraft;

c. If there was evidence to indicate that the MAG BRAKE switch activations and the lowering of the thrust control lever was occurring without the knowledge of the PF; and

d. If there was evidence to indicate that the MAG BRAKE switch activations and the lowering of the thrust control lever was intentional.

1.16.9 When questioned regarding the normalcy of the observed MAG BRAKE switch activation rate, some experienced CH147F pilots felt the rate was unusually high. The investigation therefore considered the possibility that the MAG BRAKE switch activations, and the lowering of the thrust control lever, had not been intended and occurred unbeknownst to the PF.

1.16.10 Testing was conducted to establish the maximum rate at which a person could physically press and release the MAG BRAKE switch to achieve activation. Activation rates as high as five activations per second were found to be achievable (in a test environment). Also, the OEM provided information coming from an internal flight test program where rates as high as three activations per second were achieved by flight test pilots[61]. Based on QETE's testing, and supported by the OEM internal flight test program, the investigation determined that activation rates greater than two activations per second are achievable.

1.16.11 To determine if high activation rates were common across pilots and/or aircraft, the investigation examined FDR data spanning 60 flights, 15 aircraft, and 38 pilots. In addition to analysing FDR data, the investigation also recorded the MAG BRAKE switch activations in the flight simulator in Petawawa. Within individual flights the typical observed maximum activation rates over a 10 second interval ranged from

[61] CH-147 Aircraft 310 Accident, Collective Magnetic Brake Trigger Analysis (w/ Fleet Data), 2 Jul 23.

0.5 activations per second to 1.75 activations per second[62]. In most flights, regardless of pilot or aircraft, the observed maximum activation rates reached one activation per second or higher over a 10 second interval. It was concluded that high activation rates were common across pilots and aircraft. It was noted that one aspect that affects activation rates is the type of mission being flown, with a lower activation rate during instrument flying and a higher activation rate during tactical flying.

1.16.12 To assess if lowering the thrust control lever was occurring without the knowledge or intent of the PF, the investigation examined samples of CH147F fleet FDR data where MAG BRAKE switch activations exceeded one activation per second. It was found that they occurred mostly during phases of flight where fine adjustments of the thrust control lever (up or down) were necessary. Recordings in the flight simulator also observed MAG BRAKE switch activations exceeding one activation per second, again where fine adjustments were required and thrust control lever movement was intentional. While it was found that some pilots were not specifically aware of their own personal MAG BRAKE switch activation rates, the investigation found no evidence indicating unintended lowering of the thrust control lever had occurred without the knowledge of the PF.

1.16.13 The investigation found no evidence of unserviceability that points to a deficiency or influence of the MAG BRAKE functionalities during the *Hammer 31* flight, or in the review of fleet data.

Flight Dynamics Model Simulation

1.16.14 The Flight Sciences section of the DTAES, with support from the NRC, were tasked to generate a model simulation to assess aircraft recovery time. The intent of that effort was to determine at which point, both in terms of altitude and time, the pilots would have had to input flight control commands to avoid impacting the water.

1.16.15 The CH147F flight dynamics model was developed using the simulator model dataset (SMD) data, which was the same flight test data gathered to produce the Level D[63] simulator for the CH147F. The SMD contained command inputs and aircraft responses for various flight control inputs, manoeuvres, and flight conditions. NRC went through the SMD to identify manoeuvres and flight conditions of interest for modelling and validation. The flight dynamics model simulation demonstrated good agreement with the SMD for thrust control lever authority to pull out of descending flight. There is high confidence in the accuracy of the model given the thrust control lever input required for recovery was modelled from the SMD autorotation recovery, which showed good agreement during validation. As the autorotation rate of descent was higher[64] than the CH147310 FDR data, and did not consider ground effect, the simulation provides a conservative height and time for recovery.

[62] 2 activations per seconds is the maximum rate that can be recorded by the FDR, as this parameter is recorded at 4 Hz.
[63] Level D is the highest level of simulator, often referred to as full flight simulator.
[64] Up to 2900 fpm descent rate.

1.16.16 The flight dynamics model simulation of safe recovery suggested that a simultaneous cyclic and collective input at 25 ft AGL would have arrested the descent rate and have avoided the impact with the water[65]. In terms of time, this equates to an aircraft recovery time requirement of 2.0 seconds.

1.17 ORGANIZATIONAL AND MANAGEMENT INFORMATION

UNIT ORGANIZATION AND RESOURCE ALLOCATION

Staffing Levels in the Operational Training Flight (OTF)

1.17.1 450 THS is the sole unit operating the CH147F. Within the unit, the OTF is one of several subunits, or flights. In light of this construct, and the fact that the CH147F is a high-demand asset, the unit must always strike a balance between Force Employment and Force Generation.

1.17.2 The OTF is responsible for numerous courses, including BFO, TAFO, the Flight Instructor Course, Conversion Training, Recertification Training (RT), Flight Engineer Training, and Loadmaster Training. The investigation found anecdotal evidence that exercises or training events that draw aircraft and IP/Cabin crew away from the unit is one of the biggest challenges to the OTF. Aircraft serviceability was also noted as a pressure. To validate the information the investigation looked at the three Training Standardization Visit (TSV) reports from 2 CAD for the year 2017[66], 2020[67], and 2023[68].

1.17.3 The review of the TSV reports highlighted a few challenge areas, including but not limited to, high workload, courses taking significantly longer than allocated in the Training Education Plan (TEP), and lack of aircraft and/or cabin crew availability. However, one common theme across all three TSV reports is the staffing shortfall in the OTF. In 2020, and again in 2023, the TSV reports stated that a potential source of the staffing shortage was that 450 THS as a unit is staffed according to Vice Chief of the Defence Staff (VCDS) Priority Level C. It also noted that all other RCAF Training Establishments (TE) (except 438 Sqn) are at least a VCDS Priority Level B, and that 450 THS should receive special consideration to ensure it is staffed in line with the rest of the RCAF TE.

1.17.4 450 THS manages unit resources using an established priority matrix (Annex J), which is aligned with direction from 1 Wing and 1 CAD. This framework is meant to align resources to activities which is actively managed by Commanders. In essence, they have five different priority levels, each with sub-priorities, for a grand total of 22

[65] These figures would have the aircraft stop the descent at 0 ft, or at the water level.
[66] 1776-1 (SO ACGP SET), 2 Canadian Air Division – Training Standardization Visit Report, 450 Tactical Helicopter Squadron, 16-19 Oct 17.
[67] 1776-1 (SO ACSO Trg/SET), 2 Canadian Air Division – Training Standardization Visit Report, 450 Tactical Helicopter Squadron, 24-26 Feb 20.
[68] 1776-1 (SO TSV Coord), 2 Canadian Air Division – Training Standardization Visit Report, 450 Tactical Helicopter Squadron, 28 Feb to 2 Mar 23.

priorities. The matrix shows that Core FG (Initial Training), which includes BFO & TAFO courses, is priority 3D (or 10/22).

Staffing Levels in the ALSE Section

1.17.5 At the time of the accident, due to unit restructuring, the ALSE section was staffed by only one full-time technician. All other ALSE technicians had been reassigned to first-line or second-line maintenance crews. Those technicians were called into the ALSE shop on an "as required basis" to complete daily ALSE tasks. The unit recognized the potential difficulty in maintaining the proper maintenance records/standards and re-instated full-time ALSE technicians in the ALSE section.

1.17.6 An Aircraft Maintenance Standardization & Evaluation Team (AMSET) audit was conducted in Oct 22. This AMSET audit was conducted before the ALSE section was restructured, as described above. A review of the AMSET audit report observations and their associated Corrective Action Plan (CAP) was carried out. Of the 26 observations, six were related to ALSE, and three of those six were not fully rectified. These three observations are as follows:

a. Improper fitting of helmets utilizing the Zeta III liner. The Zeta Liner itself is available in three different manufactured thicknesses (3/8, 1/2 and 5/8 in). However, the only thickness available in the Squadron ALSE Shop was 3/8 in, as a result it was the only thickness installed on all HGU-56/P-CF helmets. This resulted in improper fittings of helmets requiring 1/2 in or 5/8 in liners. (CAP-6651-2022-NC09)

b. Missing/incorrect technical references on E363 maintenance records. A random sampling of E363 maintenance records identified that while some record entries capture the appropriate reference, many of the recent entries use the wrong reference, or no reference at all.
(CAP-6651-2022-NC03)

c. Multiple personal ALSE gear were found with expired periodic inspections. Several HGU-56/P-CF helmets and CIACS6 Gen II Eagle Vests were identified with outstanding "suspended" inspections. The term "suspended" is not an approved statement on the CF363 maintenance records.
(CAP-6651-2022-NC08)

1.17.7 On 14 Nov 23, the AIA issued an immediate preventive measure to highlight the above deficiencies. Since then, 450 THS and 1 CAD/A4 Maint section confirmed that these issues have now been addressed.

MISSION ACCEPTANCE / LAUNCH AUTHORITY (MALA)

1.17.8 As detailed in the FOM, the Mission Acceptance / Launch Authority (MALA) process is a tool that will enable risk management of flight operations at the tactical level[69]. The process is divided into two distinct phases: Mission Acceptance (MA) and Launch Authority (LA). Each phase has a specific focus in terms of risk management but ultimately identifies the accumulated risk and assigns the appropriate approval authority level based on the overall mission risk.

1.17.9 1 Wing implemented the MALA process through the 1 Wing MALA Directive[70]. For the accident flight, the flying schedule was signed by an officer with delegated authority from the Commanding Officer (CO), and as such, Mission Acceptance (MA) was completed.

1.17.10 During the LA phase, the specific mission is considered against defined risks and a score is assigned for each risk area. For the CH147F fleet, this process is carried out electronically through the RCAF Hangar application using the Dispatch module. In the case of *Hammer 31*'s mission, the Dispatch module shows the LA worksheet was completed (displays as a green button with words completed) but the details of the worksheet could not be recovered. The flight authorization page indicates the flight was self-authorized by the aircraft captain (in this case the IP). The investigation generated the LA worksheet that would have been generated/submitted (included at Annex K) based on all information available.

STAFFING OF FLIGHT SAFETY POSITIONS

1.17.11 Although the CAF Flight Safety Program applies to the entire CAF, it is primarily championed and managed by the RCAF. This means that the Base Flight Safety Officer (BFSO) positions are often filled by RCAF personnel vice CA personnel. This was the case for the 4 CDSB BFSO. Since May 22, the officer holding the position of 1 Wing - Wing Flight Safety Officer (WFSO) was also double-hatted and holding the position of 4 CDSB BFSO.

1.18 ADDITIONAL INFORMATION

NVG & HUD SYSTEMS

General Description

1.18.1 The NVG are a binocular helmet-mounted device worn by aircrew that amplifies available ambient light. NVG enable aircrew to see at night and discern features in their operating environment. The binocular image intensifier displays a green monochromatic image to the eye, with the image based on amplification of differing light levels captured by the lenses. The binocular image intensifiers are both fully adjustable for objective focus, interpupillary distance (eye span), and have fore, aft and tilt adjustment.

1.18.2 The CH147F is equipped with a Day HUD and a NVG HUD; this investigation will only discuss the operation of the NVG HUD. The HUD is a monocle that is fixed

[69] FOM 2.2.2.4 Mission Acceptance Launch Authority (MALA), 21 Sep 23.
[70] 1 Wing Mission Acceptance and Launch Authority (MALA) Directive (Change 5), 19 Sep 22.

onto one lens of the NVG, usually on the dominant eye, that displays symbology generated by a combiner. The projected symbology, being in line with the NVG image intensifier, can be seen wherever the pilot is looking[71]. The device is interfaced with the aircraft to provide select instrumentation displays to the pilot without the need to look at the aircraft instrument panel, reducing the need to look underneath the NVG. The HUD has four declutter levels, commonly referred to as Pages, that the pilot can choose from.

1.18.3 All crew members of *Hammer 31* were wearing NVG (AN/AVS-9 models), with both pilots wearing the HUD. From the FDR data (1.11.13a), the investigation determined that both pilots had selected Page 2 to be displayed in their respective HUD. The HUD in the CH147F has Cruise (CRZ) and Hover pages, which are dependent on the speed of the aircraft. At the time of the accident, the aircraft was flying above 40 KIAS, consequently the set of data displayed was the CRZ page.

NVG Limitations

1.18.4 The NVG do not turn night into day. They require a certain level of illumination, either natural or artificial, to be effective and produce an image for the human eye. Also, too much light can have a negative impact causing saturation of the image, commonly referred to as “NVG wash-out”.

1.18.5 The NVG produce a monochrome video image that tends to produce a flat picture that makes depth perception difficult.

1.18.6 The FOV with NVG is limited to a maximum of 40 degrees; this limited FOV is compounded by blind spots. The CH147F SMM states the following[72]:

> *“Blind spots in the cockpit are more prominent with NVG. The crew must recognize the existence of these blind spots such as door posts, centre windshield beam etc, and make every effort to maintain a continual scan of their area of responsibility, to include those areas obscured by obstruction in the cockpit.”*

1.18.7 While wearing NVG, the pilots are required to lift their head and look under their NVG to see aircraft instruments, instrumentation not otherwise presented in the HUD; this increases pilot workload.

HUD Symbology

1.18.8 The four declutter levels can be used when more, less, or a different mix of symbology is desired. The pilots can customize the different declutter levels on a computer during the pre-flight mission planning. Figure 13 shows a generic HUD display with all the symbology (i.e. no display selected OFF).

[71] The HUD is only worn by pilots seated in the cockpit; cabin crew members do not wear HUD.
[72] B-GA-002-147/FP-001, CH147F Standard Manoeuvre Manual, Chapter 4, para 19.c. 1 Jan 18.

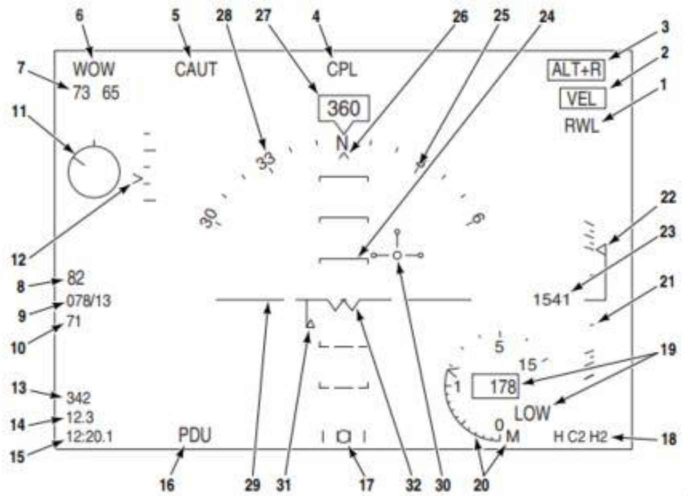

Figure 13 - HUD Display - Generic

1.18.9 The mission card was recovered from the aircraft wreckage. Using the mission card and the flight planning computer, the investigation was able to determine which elements of the symbology were selected to be displayed (1.11.14). Both pilots had programmed their HUD in an identical manner, meaning that they both displayed the same information. The elements of the HUD symbology that were closely examined by the investigation were:

HUD symbology	**Item number (Figure 13)**	**Displayed on NVG Page-2 (1.11.13a) (*Hammer 31* pilots)**
Indicated airspeed digital readout	8	Yes
Ground speed digital readout	10	Yes
RADALT altitude digital readout & low warning indicator	19	Yes
RADALT scale, pointer, drag line	20	No
Vertical speed indicator – scale	21	Yes
Vertical speed indicator – pointer & drag line	22	Yes
Barometric altitude readout	23	Yes

Table 7: NVG-HUD symbology of interest to the investigation

1.18.10 Figure 14 is derived from Figure 13 above, edited to show only the elements of the HUD symbology that were selected to be displayed by the pilots of *Hammer 31*. This is a depiction of what the pilots would have seen through their respective HUD.

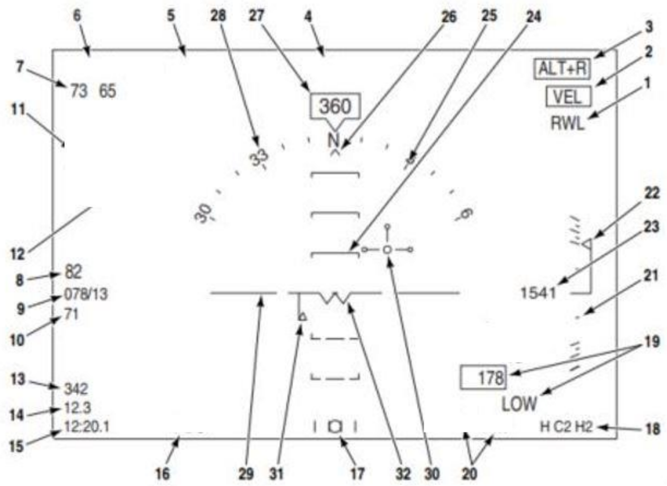

Figure 14 - HUD Display - Hammer 31

<u>NVG & HUD Systems Failure</u>

1.18.11 The NVG and the HUD are separate systems. The only interaction is the physical attachment of the HUD on the NVG mount to be in line with the binocular image intensifier. The NVG needs to be functional in order to see the HUD information.

1.18.12 A failure of the NVG would be immediately recognized by the aircrew as they would not be able to see at all since the binocular image intensifier would not generate any image. Other than the simulated NVG failure scenario that the SP was exposed to on their second take-off, there was no evidence of NVG failure.

1.18.13 A failure of the pilot HUD Display Unit will display a “FAIL” message on the HUD. The FDR has a recording channel that records HUD failure. Based on the FDR, and supported by the CVR audio recording, there was no evidence of a HUD failure.

1.18.14 The investigation concluded that the pilots’ NVG & HUD were functioning and did not contribute to the accident.

NVG OPERATIONS

1.18.15 The NVG limitations mentioned above, coupled with the physiology of the human eye, will impact the aircrew in various, interconnected ways during flight operations. Some examples of such flight operation conditions are as follows:

a. Flying from a low illumination to a high illumination area;

b. Flying from a high illumination area to a low illumination area (eyes require an adaptation period to low light levels); and

c. Flying over a low contrast area.

1.18.16 Each of these flight conditions will bring their own set of challenges to the aircrew. For example, flying over a low contrast area will make it difficult for the aircrew to assess forward motion and height over an obstacle. This challenge is exacerbated if the aircrew is flying in low illumination conditions. Flying from a low illumination area into a high illumination area will cause the NVG to "wash-out" as explained above. The wash-out effect will in turn make it more difficult for the crew to discern contrast and see obstacles. Conversely, flying from a high illumination area into a low illumination area will create a "Black Hole" effect. All these effects are also exacerbated by the human eye which requires time, sometimes up to a few minutes, to adjust to changing light levels.

1.18.17 Transport Canada published an Advisory Circular[73] which defines Black Hole effect as:

> *"Black Hole means any area where a combination of meteorological conditions and the celestial, lunar or cultural illumination do not provide pilots sufficient external visual cues to see terrain and ground objects and this effect does not provide a discernible horizon sufficient to maintain control of the aircraft by external reference during night Visual Meteorological Conditions (VMC) flight."*

1.18.18 As for the danger associated with Black Hole effect, Transport Canada further states that[74]:

> *"Black Hole effect increases the danger of descending below a normal flight path during take-off or landing particularly when the flight path is over water or dark featureless terrain and it can be further intensified if the only visual stimuli are lights located on and/or near the aerodrome."*

1.18.19 Contrast is an important factor when operating with NVG. In high illumination scenarios NVG are relatively good at allowing aircrew to detect contrast, however, in low illumination conditions contrast is more difficult to ascertain. For pilots to determine their distance from and height above terrain there must be features with discernible contrast. The more features that are available, such as cultural or natural features, the higher the chance that contrast between the objects can be used to discern details to judge distance and height from the objects. In the case of low contrast surfaces such as water, sand, or snow with no defining cultural or natural features and thus less detail, the more difficult it is to perceive distance or height. Under low illumination conditions low contrast effects are exacerbated by further degradation of image quality displayed by the NVG making contrast and details more difficult to perceive. Without contrast one object or surface cannot be resolved from the other and the user will only see a solid unfeatured image.

[73] Transport Canada Advisory Circular No. 603-001, Special Authorization for Night Vision Imaging Systems Operations, 31 Mar 20.
[74] Ibid.

Orders Related to NVG Operations

1.18.20 Orders that pertain to NVG and night low level flight operations are dispersed amongst the FOM and the various fleet SMMs, and in some cases the MALA. The FOM section dealing specifically with NVG operations is “2.3.11 - Part 11 - Night Vision Goggles Operations”. This section of the FOM has been deleted since 21 Sep 22. The FOM version that was valid prior to 21 Sep 22 contained the following three statements:

> *“The content of this Order is prescriptive and deals with techniques and procedures more suitable for a Standard Manoeuvring Manual (SMM) or Standard Operating Procedures (SOP) manual.”;*
>
> *“The intent of this Order is to promulgate Tactical Aviation experience for the benefit of all current and future NVG operators. Consequently, this Order provides the foundation guidance for all fleets for the development of their own fleet specific procedures. Once steady state NVG operational status has been achieved across all fleets, this Order will be deleted.”*; and;
>
> *“When clear sky illumination level is forecasted to be 1.5 millilux and below, local ambient in-flight light is required to permit precise navigation, accurate estimation of height above ground/water and closing speed towards obstacles. Accordingly, adjustment to mission profile and speed limits shall be made or flight cancelled following an appropriate in-flight assessment by the Aircraft Captain (AC).”*

1.18.21 Since this FOM section deletion, NVG operation guidance and restrictions have been migrated to individual fleet SMMs and MALA (1.17.8). The CH147F SMM[75] details the NVG considerations such as aircraft lighting, ambient light, and cultural lighting; and the MALA is used to manage risks associated with low illumination levels. An illumination level below 0.85 mlx raises the score for this risk factor to high.

1.18.22 As a basis for comparison, the investigation looked at other rotary-wing fleets operated by the RCAF. In general, the SMMs provide similar guidance, however, individual fleet MALA are using different illumination levels to assess risk; see Table 8:

[75] B-GA-002-147/FP-001, CH147F Chinook Standard Manoeuvre Manual, Chapter 4, 1 Jan 18.

Fleet	Item	Low	Medium	High	Severe
CH146 Griffon	Illumination (mlx)		Illum (0.85<mlx<3)	Illum (< 0.85 mlx)	
CH147F Chinook	Illumination (mlx)		Illum (0.85<mlx<3)	Illum (< 0.85 mlx)	
CH148 Cyclone	Illumination	Day	Night	Illum (< 1.5 mlx)	
CH149 Cormorant	Night Anticipated Enroute or On Scene?		Yes[76]		

Table 8: Impact of illumination on MALA of RCAF rotary-wing fleets

Allies Orders Related to NVG Operations

US Army

1.18.23 Similar to the RCAF MALA, the United States Army also applies a risk model for the use of NVG in low light conditions. However, their risk model documentation was not shared with the investigation, so a determination of the illumination levels they use could not be made.

United Kingdom (UK) Royal Air Force

1.18.24 The UK Royal Air Force (RAF) have a more restrictive NVG regulatory framework which encompasses training requirements, illumination, and altitude restrictions. The RAF also use a similar generation of NVG as the RCAF. The RAF describe illumination levels as “Green Illume” and “Red Illume”. The RAF Chinook Force Flying Guide defines Red Illume as:

> “*Red Illume conditions are defined as a period of the night where there are insufficient natural ambient light levels for Night Vision Goggles (NVG) to provide sufficient references or contrast to allow unaided field landings and low-level flying techniques to be employed. The millilux level at which Red Illume conditions exist will change with the specific environment but, as a guide only, light levels forecast below 10 millilux in an area with no cultural lighting and low contrast such as desert are likely to create them”*

1.18.25 Unless Red Illume conditions exist, or infrared radiation sources to illuminate the landing site (i.e. aided field landing) is used to reduce aviation risk, the illumination status is considered Green Illume.

1.18.26 The RAF uses a tiered qualification level for their crew’s NVG qualification. Based on their respective qualification levels the crew are limited in how low they can fly. The minimum altitudes corresponding to each qualification levels are as follows (Table 9):

[76] It should be noted that CH149 fleet considers all night flying away from the airfield as medium risk.

NVG Qualification Level	Minimum Altitude
Level A	100 ft AGL
Level B	200 ft AGL
Level C	250 ft AGL

Table 9: RAF NVG minimum flying altitudes

1.18.27 The RAF Chinook Force Flying Guide prescribes a descent procedure to be used in Red Illume flying conditions. The descent procedure is a step-down approach and states the following:

> "*Crews should consider using an initial gate of 500 ft AGL to assess terrain and visibility, before descending further to set up for the approach.*"

Other Directives Related to Night and/or NVG Operations

1.18.28 In addition to the aforementioned RCAF orders, of the three AIFs 450 THS published on 26 Jun 23 (post accident), two were related to night flight operations (Annex I). AIF 23-19 was targeted specifically at flight operations in low illumination conditions and AIF 23-20 was targeted specifically at overwater flight at night.

1.18.29 AIF 23-19 imposed temporary unit restrictions in that the minimum height authorized for low flying training at night in illumination levels of 1.5 mlx or less is restricted to 100 ft Above Highest Obstacle (AHO) and that the minimum height authorized for low flying training at night overwater, regardless of illumination level, is 100 ft AHO. The AIF is more restrictive than the FOM value of 50 ft on NVG.

1.18.30 AIF 23-20 was published as a new temporary unit SOP to supplement SMM Task 200 – Perform Terrain Flight. It mandated the use of Native modes ALT (or ALT+R) as a mandatory automation mode to be used when flying at night at or below 200 ft AHO, and over any bodies of water. While the SMM does mention the use of Native modes, it only states that the technique "can be used". The AIF mandates the use of Native modes, hence making it more restrictive than the SMM.

PREVIOUS INVESTIGATIONS

1.18.31 On 10 Sep 2015, a low level flight over the water Flight Safety occurrence[77] involved a CH147F that few as low as 26 ft over the water as they were setting up for a helocasting[78] profile. The PF was forced to continually scan inside at the RADALT, as the NVG / HUD was shaking to the point it was unreadable, in the low light / low reference conditions. This occurrence did not result in water impact but had the potential to.

[77] FSIMS 165920, Controlled Flight Towards Water, 10 Sep 15.
[78] A helocast is a technique to allow special operation forces to insert into an area by jumping directly from a helicopter into water.

CH147F FIRST OFFICER COURSE

Qualification Standard and Training Education Plan

1.18.32 The CH147F First Officer Course is governed by its corresponding Qualification Standard (QS)[79] and TEP[80]. As per the Air Force Order 5007-2[81], the QS is developed and controlled by 2 CAD HQ, which assigns Senior Staff Officer Tactical Aviation (SSO Tac Avn) from 1 CAD HQ as the office of primary responsibility to do senior staff oversight for this particular course. The TEP developed and controlled by the TE, which in this case is 450 THS, describes the manner in which the TE plans to meet the requirements of the QS. More specifically, the CH147F First Officer Course is taught by the 450 THS OTF which is one of the flights within the unit. Members are granted the CH147F First Officer qualification upon successful completion of BFO course and TAFO course. The BFO course consists of three phases: Basic Day, Instrument, and Basic Night. The TAFO course consists of two phases: Advanced Day and Advanced Night. The TEP also covers and accounts for RT which is aimed at training pilots coming from another aircraft type onto the CH147F or previously qualified CH147F pilots who come back to 450 THS after an out-of-unit tour (e.g. ground tour).

1.18.33 The QS describes the performance objectives required of a member holding a qualification. Essentially, these performance objectives are standards of performance for a member to perform the duties associated with the qualification.

1.18.34 The TEP details the training strategy the TE intends to use to meet the requirements of the QS.

1.18.35 The TEP prescribes various training criteria for the delivery of the course. The relevant criteria to this investigation are:

- Training duration;
- Session capacity;
- Flying time;
- Requirement for review trips;
- Instructional Staff;
- Resource requirements; and
- Black Hole effect.

Training duration

1.18.36 The TEP stipulates that the approved course design allocates 152 training days. Not considering statutory holidays, 152 training days would equate to 30.5 weeks. The specific course that the four SPs were attending (BFO 2102 and TAFO 2202)

[79] RCAF Qualification Standard – CH147F First Officer Course, Version 2.1, 4 Mar 22.
[80] RCAF Training Education Plan – CH147F First Officer Course, Version 4.0, 15 Dec 19.
[81] Air Force Order 5007-2, Royal Canadian Air Force Individual Training and Education, 27 Mar 12.

started on 22 Nov 21, with the first SP completing the course on 15 Jun 23[82]. The period from 22 Nov 21 to 15 Jun 23 corresponds to 571 calendar days, or 81.5 weeks. This means that the BFO 2102 and TAFO 2202 course took 2.6 times longer than authorized by the TEP. Although this calculation does not consider statutory holidays and vacation leave, the investigation determined that BFO 2102 and TAFO 2202 were significantly extended. The course delays far exceeded the TEP buffer day allocation of 16 buffer days for the BFO course and 8 buffer days for the TAFO course.

1.18.37 The investigation looked at the previous course for comparison, which was BFO 2101 and TAFO 2201. BFO 2101 started in Apr 21 before transitioning into TAFO 2201 in Jan 22 to finally conclude in Aug 22. The period from Apr 21 to Aug 22 represents almost 74 weeks, again far exceeding the 30.5 weeks that 152 training days would equal, exceeding the time authorized in the TEP by a factor of 2.4.

Session capacity

1.18.38 The TEP stipulates that the optimum course loading per session is four, with the minimum being two and the maximum being eight. BFO 2102 and TAFO 2202 had four SPs, which means the course met the optimum course loading. However, the investigation found that TAFO 2201 had to be paused from late Jan to mid May 22. During that period, the OTF had a total of ten SPs on four separate courses: TAFO 2201 (3 x SPs), BFO 2102 (4 x SPs), RT 2101 (2 x SPs), and RT 2102 (1 x SP).

1.18.39 There are no provisions in the TEP as to the number of courses that can be conducted simultaneously. The only factor for consideration is the course loading. The TEP stipulates that conducting sessions at the maximum capacity (8) within existing resources for a limited number of sessions could become unsustainable.

Flying time

1.18.40 The TEP stipulates that the estimated flying hours required to complete the BFO course is 158 flying hours per course member, which includes simulator time. For the TAFO course it is estimated at 82 flying hours. A student's total remedial flying time shall not exceed 10% of the total prescribed course flying time (240 flying hours for BFO & TAFO); students that do not meet the standard within these flying hours risk removal from the course. The SP had accumulated 188.8 course flying hours on the CH147F.

Requirement for review trips

1.18.41 The topic of review trips is covered in two locations in the TEP: under the section for Course Time Allocation, and again under the section for Maximum Permissible Time between Training Events. The investigation noted that there are inconsistencies between those two sections, in that one uses "days" and the other uses "weeks" as a basis to measure whether review trips are required. Additionally, the approval level required for additional review trips varies across both sections. The most notable inconsistency, however, relates to how each section defines a review trip's

[82] Students Progress Books.

effect on calculated course time. The Course Time Allocation section states that "review trips should be non-course time" whereas the section for Maximum Permissible Time between Training Events states that "a review trip shall be counted as course flying time". For comparison, the investigation looked at the CH146 TP[83], CH148 TEP[84], and CH149 TEP[85] (i.e. all other rotary-wing fleets operated by the RCAF). The CH146 TP stipulates that review trips accrued during CH146 training should not be calculated as course time. The CH148 TEP and the CH149 TEP make no mention of whether review trips should be counted as course time or not.

1.18.42 The investigation used "days" as per the section for Maximum Permissible Time between Training Events to assess the requirement for review trips. This section states that "The maximum permissible time between training events is 15 calendar days. The maximum permissible time between a training event and a Performance Check is 7 days…Should an extended period of time elapse between training events or the basic day/advance day phases or basic night/advance night an additional review trip(s) shall be allotted at a rate of:

- 15 to 28 consecutive days – one review trip;
- 29 or more consecutive days – two review trips;"[86]

1.18.43 The BFO 2102 and TAFO 2202 course progression and continuity is depicted in graphs in Annex D. The distribution of the training events (actual flights & simulator flights) shows important breaks in their training. Based on the SP's Progress Books (Prog Book) and their Pilot Logbook, the investigation established the following breaks for the occurrence SP. Only the breaks that were longer than seven days have been closely examined. The breaks were in the following periods:

- Break #1: 11 to 22 Mar 22 (12-day break);
- Break #2: 12 Jul to 13 Sep 22 (64-day break);
- Break #3: 22 to 28 Sep 22 (8-day break);
- Break #4: 22 Oct to 20 Nov 22 (30-day break);
- Break #5: 30 Nov 22 to 10 Jan 23 (43-day break);
- Break #6: 10 to 20 Feb 23 (11-day break); and
- Break #7: 16 Mar to 3 Apr 23 (20-day break).

1.18.44 A correlation between the breaks and the TEP showed that Breaks #1, #3, #5, and #6 did follow the TEP procedure for granting review trips. In accordance with the TEP procedures, Breaks #2, #4, and #7 would have all required one or two review trip(s) depending on the length of the training break but none were granted. A closer look at Breaks #2, #4, and #7 showed that they all occurred in between course phases within the course itself (e.g. between the basic day phase and the instrument flight

[83] CH146 Griffon Tactical Aviation First Officer Training Plan, Version 3.2, 26 Apr 2023.
[84] CH148 Cyclone Co-Pilot Training Education Plan, Version 4.3, 14 May 2024.
[85] CH149 Cormorant Search and Rescue (SAR) First Officer Training Plan, Version 0, 24 Oct 2008.
[86] RCAF Training Education Plan – CH147F First Officer Course, Version 4.0, 15 Dec 19.

phase). There are no provisions in the TEP stating that the requirement for review trips does or does not apply for training breaks that occur in between course phases. However, their omission suggests that OTF views breaks between phases differently than breaks within a given phase, resulting in no review trips granted in those cases irrespective of break duration.

Instructional Staff

1.18.45 The TEP stipulates that the IP to SP ratio should be 1:1 for the BFO course and 1:2 for the TAFO course. A review of the established positions and filled IP positions at 450 THS indicates this ratio can easily be met.

1.18.46 The investigation looked at IP assignments to assess instructor continuity for each SP. For BFO 2102 and TAFO 2202 it was determined that two of the SPs flew with 12 different IPs, while the other two SPs flew with 13 different IPs. The IP assignment distribution is shown in Table 10. This represents instructor continuity for each SP.

IP#	SP 1	SP 2	SP 3	SP 4
1	31	28	7	10
2	1	1	3	2
3	1	0	26	26
4	2	1	1	2
5	0	1	1	1
6	5	7	3	4
7	4	8	5	9
8	3	3	4	3
9	3	2	3	2
10	20	12	19	12
11	3	4	4	1
12	1	1	3	1
13	10	20	14	18

Table 10: Number of flights each SP flew with each IP

1.18.47 Using the Prog Books and the Pilot Logbooks the investigation determined that not all 13 x IPs were coming from the OTF. Many were coming from other sections within the unit, and from 1 Wing HQ. Multiple IP changes throughout a course could lead to continuity and/or standardization issues in the delivery of the course. Combining Table 10 with information from each SP's Prog Book the investigation identified the number of IP changes as follows:

	SP 1	SP 2	SP 3	SP 4
#Flights	84	88	93	91
#IP changes	50	53	44	52

Table 11: Number of flights versus IP change for each SP

1.18.48 In the case of SP 1 who flew most of their flights with IP 1 (31 flights), if SP 1 changes IP for a single flight this will account for two IP changes, one change going from IP 1 to another IP, and then one change for coming back to IP 1. IP changes presented in Table 11 are only an indication of how many times these changes occurred. It is important to highlight that IP changes do not directly relate to instructor continuity. The investigation recognizes that IP changes for the conduct of flight tests is a normal and desired practice to achieve an objective assessment of the SP.

Resource Requirements

1.18.49 The investigation looked at the TEP, Annex E – Resource Requirements, to examine how many aircraft are dedicated to the OTF in order for them to meet their training mandate. The TEP does not mention the number of aircraft required to conduct the courses. As a basis for comparison, the investigation looked at the CH149 Cormorant TEP[87] and noted that this TEP specifically assigns one aircraft dedicated to the 442 Transport & Rescue (T&R) Sqn OTF. The CH149 TEP was specifically selected for this comparison since both 450 THS and 442 (T&R) Sqn have the same construct, in that they are operational units with an embedded OTF.

Black Hole effect

1.18.50 A review of the TEP found no specific mention of training/exposure requirement with respect to the *Black Hole Effect*.

HELICOPTER AERODYNAMICS – ROTOR FORCES DURING TURNS

1.18.51 During straight and level flight, the forces from the main rotor must equal the weight of the helicopter as depicted in the first helicopter in Figure 15. During a turn, the helicopter will bank to some angle, and as a result, the thrust remains in line with the vertical axis of the banked helicopter, as depicted in the second helicopter in Figure 15. The angled rotor forces can be split into a vertical and horizontal component; the vertical component will counteract the weight of the helicopter and the horizontal component will act as the centripetal force to affect the turn. To maintain altitude, the vertical component will need to be equal to the weight of the helicopter, which can only be achieved if the total rotor thrust exceeds the thrust normally applied in straight and level flight by a load factor that is a function of the aircraft bank angle. The larger the bank angle, the larger the load factor will be, and the more rotor thrust will be needed, as depicted in the third helicopter in Figure 15. The load factor translates into a "G" force applied to the aircraft and aircrew (see Table 12).

[87] TEP - CH149 Cormorant Search & Rescue (SAR) First Officer, 24 Oct 08.

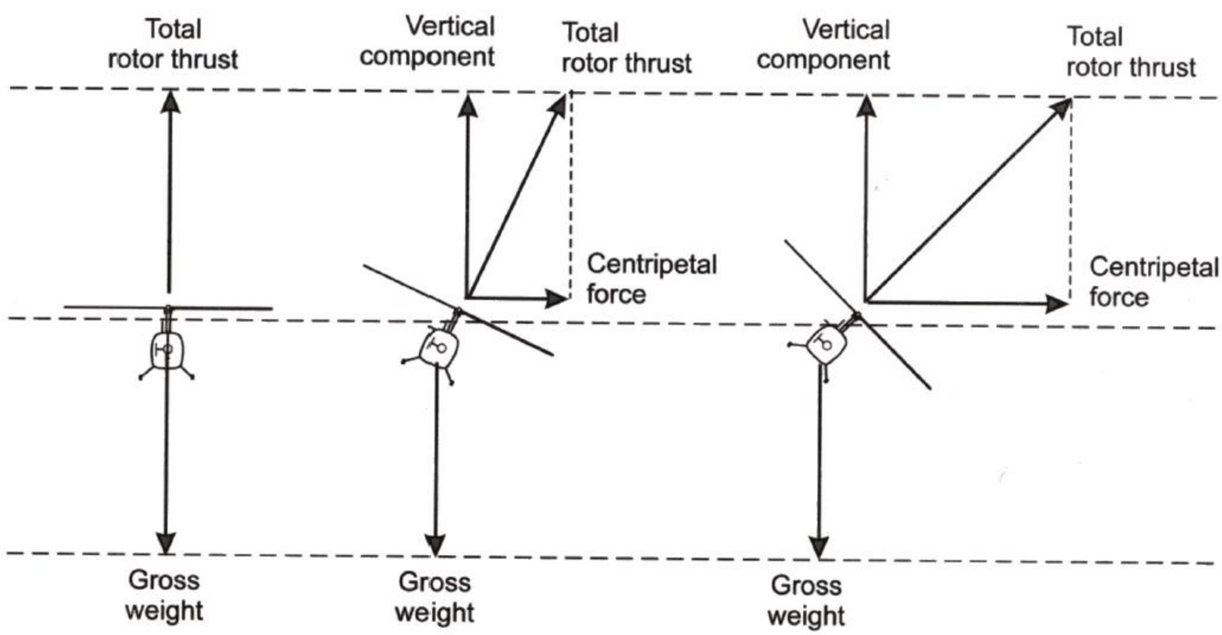

Figure 15 – Relationship between angle of bank and requirement for total rotor thrust to provide the vertical component and centripetal force[88]

Bank Angle	**Rotor Thrust – Load Factor**
15º	1.04G (or 1.04 x the weight)
25º	1.10G
30º	1.15G
35º	1.22G
45º	1.41G
60º	2.00G

Table 12: Rotor (and aircrew) load factor during a turn at constant altitude

1.18.52 During a turn, in a situation where the load factor applied to the helicopter is above or below the one quoted in Table 12, the vertical component of the rotor thrust force will not equal the weight of the helicopter and it will either climb or descend. The rate of climb or descent (vertical speed) will continue to increase until the vertical forces are balanced again, at which point the vertical speed attained will remain constant (i.e. trimmed flight).

[88] Principles of helicopter flight, Walter J. Wagtendonk, second edition revised 2006.

SMM INFORMATION

Standard Crew Duties

1.18.53 Chapter 1 of the SMM lists the crew duties assigned to each crew member. Every crew member is responsible for aircraft safety and for traffic and obstacle avoidance. The crew duties relevant to this investigation are:

a. The PF, occupying either the right or left seat has active control of the aircraft. Regardless of the level of automation employed, the PF will maintain a visual scan and crosscheck systems and instruments.

b. The PM, occupying either the right or left seat but not in control of the aircraft, is responsible to navigate and crosscheck systems and instruments. The PM shall also monitor the PF's actions to detect, trap and mitigate errors and threats to the safety of flight.

c. The FE is to assist in traffic and obstacle avoidance/clearance for the area between 2 o'clock to 10 o'clock via the 6 o'clock[89]. The FE is also responsible for matters concerning the cabin area, slung loads, specified mission kits, and technical aspects of the aircraft.

Standard Crew Terminology

1.18.54 Standard crew terminology is detailed in Chapter 1 of the SMM. It provides a list of standard words or phrases that aircrew shall use in all environments (day and night). The standard crew terminology that is relevant to the investigation was:

a. Moving Up/Down. Given by the PF. This indicates that the PF will initiate an ascent or descent;

b. Back to Cruise. Given by the PF. This indicates that the aircraft is exiting the critical phase of flight. The PM can then resume normal PM duties (i.e. prior to the Back to Cruise call the PM is "standing by" the controls and ready to take control of the aircraft as required given an emergency situation);

c. Left/Right Seat Inside/Outside. Given by either the left-seat or right-seat pilot. This indicates that the specified position's focus is inside the cockpit or back to normal duties (i.e. outside); and

d. Any command three times. The repetition of any command three times indicates imminent danger, which requires immediate action (e.g. Up Up Up, Left Left Left).

[89] Not specifically mentioned in the SMM, but it is accepted practice for the cabin crewmember at the door to be responsible for ensuring clearance from obstacles on the right side and below the aircraft, while the cabin crewmember at the ramp is responsible for ensuring clearance on the left side of the aircraft.

1.18.55 There is no standard crew terminology defined for when the RADALT low altitude warning tone is heard, only that the PF needs to verbally acknowledge and take action (1.18.57). Although not mandated by the SMM, the investigation found anecdotal evidence that aircrew have adopted a best practice that when the RADALT tone is not acknowledged by the PF, another member of the crew would state “RADALT – Move Up” to cue the PF to take corrective actions.

RADALT Setting

1.18.56 RADALT low altitude warning setting is also detailed in Chapter 1 of the SMM. The RADALT setting recommended for terrain flight (night) is 20% below the lowest planned transit height (AGL or above forest canopy) to a minimum of 40 ft.

1.18.57 The RADALT setting section also contains the following statement and note:

> “*The PF shall verbally acknowledge audio alert activation, and action being taken. Do not cancel alert via the cyclic ACK switch until acknowledging and correcting/stating the reason for the activation*.”

NOTE: “*Not required when RADALT audio is expected on approach.*”

Task 109: Perform VMC Flight Manoeuvres

1.18.58 Task 109 of the SMM defines the procedures for level flight and turns in flight. Under the section for turns in flight, the following three statements were relevant to the investigation:

> *“The helicopter handles well during level turns. Any prolonged turn will require some additional thrust to maintain altitude and speed.”*;
>
> *“Bank angles up to 30 degrees for short duration require no appreciable increase in thrust, but bank angles greater than 30 degrees will require additional thrust.”*; and
>
> *“The PF shall remain focused primarily outside the aircraft and shall announce significant climbs and descents. Turns shall be announced when the aircraft heading will change by more than 60 degrees as a result of the turn.”*

Task 200: Perform Terrain Flight

1.18.59 Task 200 of the SMM defines the various standards, procedures, environmental considerations, and crew management principles to effectively and safely operate the CH147F in the low-level environment (defined as below 300 ft AGL).

1.18.60 The standard procedure of setting the RADALT low altitude warning to 20% below the planned minimum transit height is also repeated in Task 200 for emphasis.

The minimum altitude for CH147F operation is governed by the FOM[90]. It states that the minimum height, at night operating with NVG, is to be no lower than 50 ft AHO within ½ rotor diameter. This would correspond to the RADALT being set at 40 ft, in line with the SMM.

1.18.61 Task 200 has a specific section addressing overwater considerations. The following is an excerpt from this section:

> *"Overwater flight, at any height, is characterized by a lack of visual cues, and, therefore, has the potential to cause visual illusions.*
>
> *In order to minimize spatial disorientation and avoid an unintentional descent to the water, the following techniques can be used:*
>
> *a. follow shorelines of bodies of water rather than crossing the middle;*
>
> *b. use Native modes to maintain height; and*
>
> *c. increase height above the water, particularly on dark nights when there is little wind and the water is glassy."*

1.18.62 None of those three mitigating measures were used by the crew.

1.18.63 The requirement for the PF to announce turns that will result in heading changes of more than 60 degrees (as per Task 109 above) is also repeated in Task 200 for emphasis.

1.19 Useful or Effective Investigation Techniques

Nil

[90] FOM 2.2.6.3 - Minimum Altitudes.

2. ANALYSIS

2.1 GENERAL

2.1.1 The aircraft was serviceable, and the crew was current and qualified for the mission. The investigation determined that the unrecognized, constant descent of the aircraft over the final 19 seconds of flight led to a situation where the aircraft was not recovered before impact. The investigation focused on how the aircrew did not recognize this condition, and how they acted (or did not act) prior to impacting the water. The emergency response was also reviewed to examine survival aspects related to the accident. The investigation encompassed multiple lines of investigation; the analysis portion of the report is divided into the following areas:

a. Increasing rate of descent;

b. Pilot Intentions with respect to the initial descent;

c. Acceleration forces;

d. Black Hole effect;

e. Pilot Intentions with respect to the constant rate of descent;

f. Flight instruments & rate of descent monitoring;

g. Flight control inputs;

h. Crew workload;

i. Spatial disorientation;

j. RADALT management;

k. Organizational factors;

l. Emergency response; and

m. Survivability aspects.

2.2 INCREASING RATE OF DESCENT

2.2.1 Based on FDR data (see graph of selected FDR parameters at Annex G), a slow increasing rate of descent took place during the period of the turn when the bank angle was at its maximum of approximately 36 degrees (See black-dotted trace when FDR file time is between 12170 to 12177 seconds – Figure G-3 Annex G). After that period, the bank angle was reduced, and the rate of descent (vertical speed) remained relatively constant at approximately 1000 fpm (16.7 fps on red-dotted trace – Figure G-3 Annex G).

2.2.2 FDR data indicates that for a 7-second period, when the aircraft was banked to approximately 36 degrees, rotor thrust load factor was around 1.0G. Maintaining a constant altitude at this bank angle requires a load factor of 1.24G (1.18.51), meaning that, for this 7-second period, the crew of *Hammer 31* did not apply sufficient thrust or set the proper attitude to maintain level flight (SMM – 1.18.58), resulting in a slow but increasing rate of descent.

2.3 PILOT INTENTIONS WITH RESPECT TO THE INITIAL DESCENT

2.3.1 The crew brief stated the intent to do a tactical navigation leg direct to the T40 confined area; which implies an altitude of 50 ft (1.18.60); consequently, the crew expected a descent at some point following the takeoff from FATO 17. The investigation considered two possible scenarios to explain the initial descent:

a. The initiation of the descent was intentional, with an intent to level off once tactical altitude was reached; or

b. The initiation of the descent was unintentional.

2.3.2 Using CVR, FDR data and FDR events (Numbered from 1 to 7) highlighted in Figure G-3 (Annex G), the investigation assessed the following factors to make a determination regarding pilot intentions:

a. “Moving Down” call. As per the SMM, it is standard practice to call “*Moving Down*” prior to initiating a descent. Although not specifically mentioned in the SMM, to limit excessive communications in the cockpit, “*Moving Down*” calls may be omitted when: (1) only small changes in altitude are made, or (2) it was understood/expected by all crewmembers that a descent would take place. In the case of the accident leg, the aircraft reached a maximum altitude of 315 AGL, which could be considered significant when operating tactically at night on NVGs. Considering the high workload, and the fact that the crew expected the descent, the call may not have been considered necessary. No such call was made in the case of this occurrence. While this does not directly indicate intention or awareness of descending, given that the IP had announced entering left-hand turn immediately prior to the descent, it is possible that a “*Moving Down*” call would have been made if it was intentional. Although the initiation of the descent might have been intentional it is possible that the initial descent was unintentional rather than the IP simply omitting the “*Moving Down*” call.

b. Handing over the controls. The turn, which was initiated by the IP, reached 36 degrees of bank and the aircraft began descending before the controls were handed to the SP. It is standard practice to advise the other pilot of initiated flight manoeuvres, such as a descent, prior to transferring control. The SP was not advised that a descent had begun prior to taking over control of the aircraft from the IP. This reinforces the idea that the descent was unintentional and not known to the crew.

c. Thrust application. When taking over the controls, the SP maintained the same aircraft attitude and thrust setting for several seconds while the descent rate increased, until the bank angle was reduced from 36 to 25 degrees. The SP then started to lower the thrust control lever once the treeline was cleared (blue trace – Figure G-3 Annex G), indicating the SP was unaware of the descent or descent rate that had already been established.

2.3.3 The investigation believes that the initiation of the descent at the start of the turn, while the bank angle was 36 degrees, was possibly unintentional, nonetheless unrecognized by the crew. As the bank angle was reduced to 25 degrees, the crew expected the aircraft to be at a relatively constant altitude. This is considered the most likely scenario to explain how the descent was initiated, which was maintained for the last 19 seconds of the flight.

2.4 ACCELERATION FORCES

2.4.1 Using FDR information, specifically the variation in vertical speed (descent rate), the investigation determined that the change in acceleration forces felt by the crew was 0.074G. Although possibly within the human body's detection range (detection ranges from 0.01 to 0.1G – 1.13.11), the 0.074G would likely be masked by the vibrational environment of a helicopter (1.13.12). Consequently, the crew may not have been able to depend solely on their vestibular system to detect the acceleration forces, resulting in an unidentified increase in rate of descent.

2.4.2 Following the 7-second period where the bank angle was approximately 36 degrees, the aircraft bank angle was reduced, and a constant descent rate of 1000 fpm (+/- 200 fpm) was maintained. As this is a condition of constant velocity, downward motion cannot be sensed by the body. Under a constant rate of descent, the crew would need to rely on visual cues (on NVG) or flight instruments to monitor their descent rate in the last 19 seconds of the flight.

2.5 BLACK HOLE EFFECT

2.5.1 Low illumination levels and glassy water are factors that can contribute to creating a Black Hole Effect for crews flying at night. The glassy water significantly decreased the level of contrast, especially using NVG, which made it difficult for the crew to accurately assess their height above water and rate of descent. The Black Hole Effect was exacerbated by the fact that *Hammer 31* was flying from a high illumination area (over the Garrison) into a low illumination area (over the river). Furthermore, the Ottawa River sitting 20 ft lower than the airfield elevation and located on the other side of a treeline is obstructed by the treeline and benefits less from the airfield illumination. When looking at the flight path of *Hammer 31* for that night (Annex G), both SP 1 and SP 2's missions were flown almost exclusively over or near land (first leg of SP 2 followed the shore in preparation for landing), except for the accident leg which was flown over the river for the first and only time that night. The environmental conditions, both the illumination level and the calm winds, created a Black Hole Effect over the

Ottawa River. The Black Hole Effect would have made it more difficult for the crew to visually assess height and descent rate while using NVG.

2.5.2 As a result of the Black Hole Effect, the ability to use visual cues from the crew's NVG was negated (2.4.2); leaving only flight instruments to monitor their descent rate in the last 19 seconds of the flight.

2.6 PILOT INTENTIONS WITH RESPECT TO THE CONSTANT RATE OF DESCENT

2.6.1 The investigation believes that the initiation of the descent was unintentional and not recognized by the crew (2.3.3); in this section, the investigation considered the possibility that during the constant rate of descent portion of the flight (the last 19 seconds of the flight), the PF may have been aware of their rate of descent but simply did not verbalize it. These factors were considered:

a. The crew brief stated the intent to do a tactical navigation leg direct to the T40 confined area, which implied an altitude as low as 50 ft;

b. The thrust control lever was lowered once the treeline was cleared; a typical location to initiate a descent;

c. The thrust lever had several manual reductions, resulting in engine torque values reducing from 59% to 18%; with such a reduction, a descent would be expected;

d. The manual thrust reductions were consistent with the execution of a constant descent rate of 1000 fpm within the +/- 200 fpm Flight Director cue satisfaction tolerance, and at least one Flight Director mode was active (1.11.13c); and

e. The descent rate of 1000 fpm is a valid and common vertical speed setting for altitude changes in radar altitude or barometric altitude mode.

2.6.2 The constant descent rate of 1000 fpm within +/- 200 fpm may indicate the PF was following Flight Director cues during the last 19 seconds; however, this is not a function that is normally used during tactical flying (VFR conditions at low altitude), and there is no such indications on the CVR (no call to indicate "*Right Seat Inside*" (1.18.54c) or any comment about Flight Director cues or set-up). Furthermore, during the last eight seconds the PF stated an intent to reduce speed, indicating their attention was not on descent rate. The investigation believes the descent was likely intentional, and although the PF might have tried to maintain the descent rate at 1000 fpm using the VSI, the pilots were not effectively monitoring the altitude and/or rate of descent to stop the descent.

2.7 Flight Instruments & Rate of Descent Monitoring

2.7.1 There are three flight instruments that can be used to make accurate assessments of altitude and rate of descent: the altimeter (based on GPS or barometric information), the VSI, and the RADALT (1.6.8).

2.7.2 The descent started at approximately the mid-point of the 61-second flight, and a constant descent rate of 1000 fpm was maintained during the last 19 seconds of the flight, while in the last 16 seconds of flight the thrust control lever was slowly but continuously lowered. As per the SMM, when the PF initiates a descent, a call "*Moving Down*" is to be made. This would create a common understanding amongst the crew of the manoeuvre to be flown, in this case a descent, and draw particular attention to altitude and rate of descent. Although the call may not have been required (2.3.2a), in the end no such verbal cues were made by either pilot to the crew. Independent from the "*Moving Down*" call, both the PF and the PM have the duty to crosscheck systems and instruments at regular intervals (1.18.53), there was ample time/opportunities to perform this monitoring. The investigation concluded that either the pilots were not effectively monitoring the altimeter/VSI/RADALT, or that the information supplied by both the flight instruments and HUD was not cognitively processed accurately. This meant that neither pilot was effectively monitoring the aircraft's flightpath, and consequently was not aware of the aircraft's rate of descent and/or altitude.

2.7.3 The cabin crew members also have a responsibility for the safety of the crew and aircraft. During the 61-second flight, there was only one mention of either altitude or rate of descent, when the Cabin Door FE called the RADALT height at 20 ft above water. Specifically, the call made was "*Height, 20 ft above water*", which was said in a normal but firm tone of voice. There were no verbal cues coming from the Ramp FE relating to altitude and/or rate of descent. The SMM defines the standard crew terminology to be used if the situation requires immediate action (1.18.54d). It states that the repetition of any command three times indicates imminent danger, such as "*Up Up Up*" to direct an immediate climb. Such a command was never given. The investigation concluded that the way the call was made indicates that the Cabin Door FE did not recognize the immediate danger. This can be explained by the fact that the Cabin Door FE was not constantly monitoring the RADALT, so when they made the call, they stated the RADALT digital readout at the time of observation. To really understand the severity of the situation, the FE would have had to monitor the RADALT more continuously to get a sense of how fast the aircraft was descending as the altitude decreased. Consequently, the investigation concluded that neither FE was aware of the aircraft's rate of descent or aircraft height and imminent danger at that point.

2.7.4 Another factor that could influence the crew's ability to monitor their flight instruments and/or their NVG-HUD is aircraft vibration. Each aircraft will have a unique vibration profile with some experiencing higher levels at lower speeds and others higher levels at higher speeds. The peak magnitude of vibrations will also vary from aircraft to aircraft. A poor fitting helmet could also exacerbate the issue, causing the helmet-mounted NVG-HUD to vibrate as well. This situation could lead to pilots spending more time inside the cockpit scanning instrumentation instead of looking outside through the NVG-HUD display. Aircraft vibration was identified as a factor in an investigation back in Sep 15 when the crew of a CH147F unintentionally flew as low as 26 ft AGL over the water (1.18.31).

2.7.5 Aircraft recorded data, both CVR and FDR, was used to assess aircraft vibration for *Hammer 31*. The crew members' voices, as recorded on the CVR, were not indicative of a high level of vibration, as they did not seem to "bounce" significantly from aircraft vibration. Also, the blade sound recorded on the CVR was not assessed as being indicative of high vibration levels. There were no comments made by the crew to indicate the aircraft was vibrating more than usual and/or that the pilots had difficulty reading cockpit instruments/NVG-HUD information. The accelerometer data recorded on the FDR did not show excessive vibrations. Furthermore, anecdotal evidence suggests that aircraft CH147310 was considered "a good flyer", albeit a subjective assessment. The investigation did not reveal any evidence to suggest that aircraft vibrations contributed to *Hammer 31*'s accident.

2.8 FLIGHT CONTROL INPUTS

TRANSFER OF CONTROLS BETWEEN THE PF AND THE PM

2.8.1 It is clearly stated throughout the SMM that, in case of imminent danger, the PM is to take control of the aircraft from the PF and correct the situation. It is an internationally recognized standard in aviation that, for the transfer of controls, the gaining pilot will state "*I have control*" followed by the relinquishing pilot stating, "*You have control*", or similar wording to this effect. The pilots of *Hammer 31* followed this procedure when the SP was subjected to the simulated NVG failure scenario, indicating not only that they were aware of the procedure but practice it as well. In the final moment of the CVR recording, there were no such verbal commands, supported by the lack of abrupt control input on the FDR recording, indicating that the PM did not attempt to take over the controls. This supports the investigation's opinion that the PM was unaware of the imminent danger.

FLIGHT CONTROL INPUTS BY THE PF

2.8.2 The FDR flight control inputs were closely examined to determine the PF's actions. To adjust and decrease a rate of descent, the PF can either pull back on the cyclic, raise the thrust control lever, or a combination of both. The flight data showed that, once the aircraft had passed over the treeline and was over water, there was minimal aft cyclic input while the thrust control lever was continuously lowered until water impact. Approximately eight seconds before impact the PF verbalized an intent to slow down, and the cyclic was pulled back sufficiently to raise the aircraft attitude from two degrees nose down to four degrees nose up. There were no large flight control inputs during that time.

2.8.3 The continuous lowering of the thrust control lever, in conjunction with the minimal aft cyclic input and prolonged aircraft nose low attitude, is not indicative of a pilot attempting to arrest a high rate of descent. This also supports the investigation's opinion that the PF was unaware of the imminent danger.

INTERFERENCE WITH THE FLIGHT CONTROLS

2.8.4 The investigation also considered the possibility of an item in the cockpit, such as ALSE or personal gear, interfering with the flight controls, resulting in the continuous lowering of the thrust control lever, however, no evidence was uncovered to support this theory.

2.9 CREW WORKLOAD

2.9.1 During the second leg of the mission, the aircraft was in the air for approximately 61 seconds. During this time, the crew was very occupied with multiple tasks and communications occurring, sometimes simultaneously. (1.11.2)

2.9.2 The left turn to T40 was initiated when the IP was flying the aircraft, and the SP was "off goggles" dealing with the simulated NVG failure scenario. Once the NVG were regained, the flight controls were handed back to the SP. At this point the aircraft was established in the left turn with 36 degrees of bank and had completed one third of the turn. The simulated NVG failure was dealt with appropriately but caused the SP to lose visual references for what was estimated to be less than 10 seconds. Also, immediately after taking back the controls, the SP had to correct a "Trim Roll right" advisory which would have brought the SP's attention inside the cockpit to look at the MFD to confirm the status of the advisory and verify it had cleared. All these actions happened just prior to, and as the aircraft was flying over, the treeline and heading into the low illumination area over the Ottawa River. The investigation believes that the time spent "off goggles" looking inside the cockpit, combined with the change of aircraft attitude proceeding into the Black Hole Effect over the river, caused the SP to lose situational awareness.

2.9.3 Although the SP started to lower the thrust control lever while over the treeline (see red line on graph of selected FDR parameters in Figure G-3 at Annex G), the aircraft was already descending at approximately 1000 fpm. Lowering the thrust control lever while the aircraft was already established in a 1000 fpm descent would not have been required in this situation. The investigation concluded that the SP was still experiencing a loss of situational awareness in that they likely considered the aircraft to be in level flight and the thrust control lever was likely lowered with the intent of initiating a descent as the aircraft was gradually rolled out of the banked turn and nosed up to halt their acceleration. The investigation believes that the SP was focussed on airspeed control as the aircraft was still accelerating towards 120 KIAS when in fact the planned and briefed airspeed for this leg was 90 KIAS; airspeed reduction would be achieved by raising the nose of the aircraft while at the same time reducing the thrust, a typical combination of flight control movement to avoid undesired gain in altitude. This factor is even more important in a tactical environment. All this also took place concurrently with an attempt to clear the Trim Roll Right advisory and the IP giving navigational instructions to T40. The simultaneous tasks to be completed after taking back the controls coupled with receiving instructions from the IP likely caused the SP to become task saturated with their attention becoming channelized on airspeed to the detriment of monitoring altitude and/or rate of descent.

2.9.4 The IP was an experienced 1 Wing pilot who had flown most of their career in Petawawa. Considered by many to be one of best pilots at the unit, the IP was well regarded and respected, and was known to follow rules and procedures. The IP's experience level should have helped mitigate task saturation to a certain degree, however, there were numerous tasks being managed simultaneously. In addition to instructor duties to assess the SP, for the last 13 seconds of the flight, the IP completed PM duties by carrying-out a *Before Landing Check* and providing navigational instructions to the SP. Both PM tasks likely brought their attention inside the cockpit, looking at cockpit instruments and the map. The IP most likely looked outside and at the instruments for brief moments, but not long enough to register the rate of descent and/or decreasing height. The CVR showed that the IP was bouncing back and forth between all these competing tasks. Also, the *Before Landing Check* was conducted in a very expeditious manner, likely because of this high workload, and was missing a few verbal cues such as the actual RADALT setting. For these reasons the investigation concluded that the IP was also likely task saturated with their attention channelized on PM duties to the detriment of monitoring altitude and/or rate of descent.

2.9.5 Another factor the investigation determined played a role in the IP's performance was fatigue. Although both the FAST and FAR indicates the IP was not considered fatigued during the initial mission brief (1.5.10), the FAST software analysis results showed that they were the most fatigued member of the crew. During the mission there were indications that the IP started to show signs of fatigue after the SP hot turn took place, two hours into the four-hour mission. For example, the IP initially indicated the incorrect FATO (though self-corrected) when advising the MFAU of their departure. Other examples included the IP not finishing or having noticeable pauses in their sentences. Although these were subtle omissions/speech changes, they are typically indicative of fatigue, and indicate the IP may not have been as alert during the second half of the mission.

2.10 SPATIAL DISORIENTATION

2.10.1 The investigation determined that, at the time of the accident, all of the spatial disorientation contributory factors, as outlined in para 1.13.7, were present:

a. Reduced FOV when using NVG;

b. Lack of references and false horizon visual illusion. The lack of contrast over the glassy water resulted in a lack of altitude references;

c. Task saturation (2.9.3, 2.9.4); and

d. Mental and physical state. The IP might have shown signs of fatigue (2.9.5), and the SP's limited experience on this platform in addition to test-related stress could have influenced their mental state.

2.10.2 Having all these factors present does not necessarily guarantee spatial disorientation, but it has been shown that both pilots missed the slow increasing rate of descent, aircraft height, and did not effectively monitor the aircraft's flightpath. The investigation concluded that the combined effects of the lack of visual references and contrast, the limited FOV while operating with NVG, task saturation, and the pilots' less than optimum mental states likely led to unrecognized spatial disorientation and continued descent until water impact. In the case of the SP, the simulated NVG failure resulted in a loss of visual ques for a period of about 10 seconds. Considering that the aircraft was no longer climbing but rather in a descending turn when the NVG were regained and controls passed to the SP, the change in flight conditions would have made it more difficult to re-orient themself.

2.10.3 Although the FEs were not task saturated, the lack of a "*Moving Down*" call by the pilots, the completion of the *Before Landing Check* (forcing their head inside as the aircraft was going over the treeline), and the lack of visual references while operating on NVG over glassy water, resulted in neither FE being aware of the aircraft rate of descent or imminent danger, indicating that both FEs were experiencing unrecognized spatial disorientation.

2.11 RADALT MANAGEMENT

RADALT BUG SETTING

2.11.1 The SMM direction for setting the RADALT bug is to adjust 20% below the minimum planned and authorized altitude. Since the mission was an Advanced Night Test, the minimum authorized altitude as per the FOM was 50 ft AGL/AHO, corresponding to a RADALT bug setting of 40 ft AGL. However, the mission card indicated the planned altitude for this leg, as well as all the other legs of the mission, was to be 100 ft AGL. This altitude would correspond to a RADALT bug setting of 80 ft. Terrain flight altitude is normally not entered on the mission card, as the crews normally fly at a height conducive to tactical flying.

2.11.2 Although the RADALT bug setting is not recorded on the FDR, the CVR indicated that the RADALT low altitude warning sounded 7.4 seconds before impact, which the FDR indicated was 125 ft, confirming the RADALT bug was still set at the value from the previous landing.

CREW REACTION TO RADALT LOW ALTITUDE WARNING

2.11.3 Knowing that the RADALT low altitude audio warning only sounded once means that the alarm was cancelled by one of the pilots in less than 1.7 seconds, which is the alarm's repeat cycle; the FDR cannot identify which pilot cancelled the alarm. The alarm was not verbally acknowledged as mandated by the SMM. Although it is the PF's responsibility to verbally acknowledge audio alert activation, and action being taken (1.18.57), either pilot could have cancelled the alarm. The investigation believes that the pilot who cancelled the alarm did it reflexively, without processing the implications, to focus on giving or receiving navigational instructions. Considering the lack of action by both pilots, it could indicate that only one of the pilots heard the alarm, which can be explained by the simultaneous communications occurring when the warning was sounded, and supported by the fact that only one FE heard the warning.

2.11.4 Given that the pilots of *Hammer 31* followed the SMM procedure for the acknowledgement of the RADALT low altitude warning during their first circuit (i.e. simulated engine chip scenario), the investigation concluded that the RADALT low altitude warning was not verbally acknowledged for one of two reasons: (1) the pilot(s) who heard the alarm were task saturated preventing further actions, or (2) the pilot(s) realized they were 125 ft above the river, which may not be alarming, but did not appreciate how fast they were descending.

2.11.5 Only one of the FEs, the Cabin Door FE, heard the RADALT low altitude warning. The investigation assessed that following the completion of the *Before Landing Check*, the Cabin Door FE was likely looking at the glassy water when the warning was heard and immediately moved to the cockpit area to look at the RADALT on the instrument panel to provide an accurate altitude reading. The call made was "*Height, 20 ft above water*", spoken in a normal but firm tone of voice. The lack of urgency, or a more assertive call like "*Up Up Up*" can be explained by the fact that the RADALT bug setting for tactical flight is normally 40 ft, hearing the RADALT would then mean a height reduction of 10 ft [down from 50 ft AHO tactical altitude]. This is further evidence that neither FE was aware of the aircraft height, rate of descent or imminent danger.

RESPONSE TIME TO THE RADALT LOW ALTITUDE WARNING

2.11.6 Based on the Flight Dynamics Model Simulation developed by DTAES and NRC, it was determined that, aerodynamically, the aircraft would have required initiating both a cyclic and a thrust control lever input 2.0 seconds prior to impact to arrest the descent rate and avoid impacting the water; this is the aircraft recovery time (1.16.16). Taking into consideration that the human Response Time to a stimulus for a situation representative of that experienced by *Hammer 31* was assessed at 3.0 seconds (1.13.15) the total time required from a stimulus to complete aircraft recovery is 5.0 seconds:

[Total Aircraft Recovery] **=** [Human Response Time] + [Aircraft Recovery Time]

5.0 seconds **=** 3.0 seconds + 2.0 seconds

2.11.7 Figure 16 is included to clarify some of the timelines before impact:

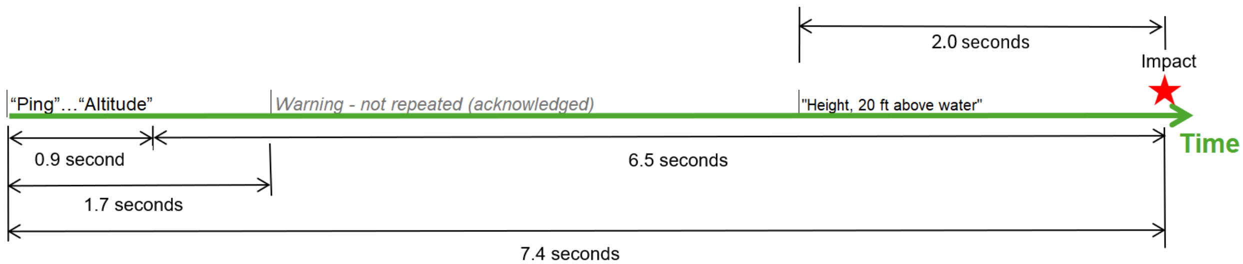

Figure 16: Timeline of select audio elements before impact

2.11.8 Knowing that the RADALT warning sounded 7.4 seconds before impact, there was theoretically sufficient time for the PF to react and avoid impact (7.4 vs 5.0 seconds). The aircraft was not recovered from its descent for three likely reasons: the pilot(s) who heard the alarm (1) did not perceive that they were in a situation that required corrective action, (2) were task saturated preventing further actions, or (3) were still processing the warning at the time of impact, which, if true, would indicate that their response exceeded the best-case scenario used as human Response Time (3.0 seconds). Numerous factors could increase this Response Time (Response Time = Reaction Time and Action Time), such as the number of response options available (requirement for a decision) and stress level, to name a few. (1.13.14). The investigation considers task saturation as the most likely scenario to explain the lack of response following the RADALT warning.

RADALT PROCEDURES

2.11.9 Given that the SMM mandates the RADALT bug to be set 20% lower than the minimum/planned altitude to be flown, the RADALT low altitude warning audio tone should rarely be heard if the crew adheres to their altitude. The SMM states that the PF shall verbally acknowledge audio alert activation and state the corrective actions being taken. This is a critical step as the RADALT is an important safety feature, and even more important considering that when it is set properly and heard the aircraft is already 20% lower than the minimum planned altitude. That said, the 20% rule is considered reasonable since setting the RADALT bug exactly at the minimum planned altitude would likely generate a large number of nuisance activations. Considering the importance of the RADALT as a safety feature, the SMM note stating that RADALT acknowledgement is not required when it is expected on approach (1.18.57) creates a situation where the PF has to make a decision on whether or not to acknowledge the RADALT tone; which may result in an increase to the Reaction Time. To train "muscle-memory" and take appropriate action every time the RADALT tone is heard (even if verbal only) it is recommended that the SMM note related to approach be removed. A trained "muscle memory" action may have allowed the SP to react even when task saturated.

2.11.10 In addition to the SMM procedure for setting the RADALT bug, there is also a requirement for the crew to verify the RADALT bug as part of the aircraft "Systems Check", which is included in the *Before Taxi Check*, the *Before Takeoff Check*, and finally the *Before Landing Check* (1.6.14). Looking at the mission profile after the SP hot turn, the RADALT should have been verified five times:

- *Before Taxi Check* (immediately after the hot turn);
- *Before Takeoff Check* (1st circuit, leading to engine chip scenario);
- *Before Landing Checks* (1st circuit, leading to the 1st landing);
- *Before Takeoff Check* (2nd leg, going to T40); and
- *Before Landing Check* (carried out during the accident turn).

2.11.11 Of the five checks above, the RADALT setting was verbalized only once, during the *Before Landing Check* leading to the landing at the end of the first leg. It is possible that the RADALT was verified "visually" the four other times but was not verbalized. A possible explanation is that the mission tempo forced the crew to compress the checklists leading to missed checks. The investigation considers the RADALT bug setting to be an important safety feature and believes that it should be verbalized and acknowledged every time it is set or verified as part of a checklist. This would ensure all crew members are continuously aware of the current RADALT bug setting. In the case of this accident, it could have greatly helped the Cabin Door FE in understanding the criticality of the situation when only 20 ft was seen on the RADALT digital display.

2.11.12 The investigation looked at several scenarios that could have possibly arrested the sequence of events that directly led to the accident. One possible scenario is the situation where the Cabin Door FE understands the critical situation and makes an assertive call "*Up Up Up*" instead of calling "*Height, 20 ft above water*". As the original call from the Cabin Door FE was made approximately 2.0 seconds before impact, it would not have provided enough time for the pilots to interpret the input, then react and recover the aircraft (5.0 seconds are needed from a stimulus to complete aircraft recovery – see 2.11.6).

2.11.13 Another scenario considered by the investigation is the situation where the RADALT was set to 40 ft as normally set for tactical navigation. In such a scenario, the RADALT tone would have sounded 3.5 seconds before impact, which would not have provided enough time for the pilots to interpret the input, then react and recover the aircraft.

2.11.14 A final scenario assessed by the investigation is if the Cabin Door FE did not wait to look at the RADALT, but adopted the best practice that when the RADALT tone is not acknowledged by the PF, "*RADALT – Move Up*" should be called (1.18.55). Considering that the end of the aural tone (ping) followed by the verbal warning "*Altitude*" occurred at 6.5 seconds[91] prior to impact, and then assuming 1.0 second to wait for the PF to acknowledge, and 1.0 second for the FE to call "*RADALT – Move Up*", this would leave 4.5 seconds for the pilot to recover the aircraft. This is less than the 5.0 seconds necessary for the pilots to recover the aircraft; however, this scenario

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[91] The RADALT warning sounded 7.4 seconds before impact, but the aural tone and verbal warning were completed 6.5 seconds before impact (Figure 16).

provides more time for the pilot to take action compared to the scenario in the previous paragraph and might have attenuated the impact. The investigation recommends that the best practice of using the command "*RADALT - Move Up*", called by another crew member when the RADALT tone is not verbalized by the PF, be formalized and included in the SMM (1.18.55). Considering that the aircraft would then already be at least 20% lower than the minimum/planned altitude, the call should be treated as an authoritative command calling for immediate and unquestionable action by the PF similar to a Traffic Collision Avoidance System Resolution Advisory (TCAS RA).

2.11.15 Although not related to the accident sequence of *Hammer 31*, the investigation's analysis of RADALT procedures on multiple helicopter fleets (i.e. CH146 Griffon, CH148 Cyclone, and CH149 Cormorant) has highlighted an opportunity for improvement in how RCAF crews use and manage their RADALT. Each fleet's SMM provides clear direction on RADALT bug setting, and each are dependent on the specific flight profile being flown (e.g. IFR, VFR, day, night, and NVG). There is, however, no clear direction on how to use and manage the RADALT when transitioning between flight profiles, more specifically from a high flight profile to a low flight profile. The investigation believes that each fleet's RADALT procedures should include clear direction when transiting from a high flight profile to a low flight profile.

2.12 ORGANIZATIONAL FACTORS

2.12.1 This section will analyse the factors at the organizational level.

STUDENT PROFICIENCY AND TRAINING EDUCATION PLAN

2.12.2 As the investigation assessed the QS and TEP for the CH147F FO course, several training criteria were reviewed (1.18.35). During the review a few of these stood out:

- Training duration;
- Requirement for review trips;
- Instructional staff; and
- Resource requirements.

2.12.3 The most evident anomaly was the SP's training duration which took over 18 months; a course that should have been completed in approximately 7 months (30.5 weeks – 1.18.36). It has been determined that this is not an exceptional situation, and that similar timelines have been observed in the past. One of the consequences of this extended training duration was the numerous breaks in between training events (actual flights & simulator flights) for the occurrence SP (1.18.43). Seven breaks exceeding seven calendar days were recorded, of which three were of 30 days or more. It was determined that three of those breaks occurred in between different phases within the course itself (e.g. between the basic day phase and the instrument flight phase); and that no review trips were allotted following these breaks, contrary to the TEP. For new students learning a complex high-performance aircraft such as the CH147F, such long breaks will have a large impact on their ability to learn and build new skillsets. The investigation could not determine to what degree these long breaks in training affected performance, but would have likely eroded the SP's proficiency, making them more prone to task saturation. Considering that a student's total remedial flying time shall not exceed 10% of the total prescribed course flying time, the investigation believes that circumstances requiring review trips that are outside a student's control should not count as course time. Counting those flying hours as course time would disadvantage the student as it would be using up flying hours in the 10% prescribed limit.

2.12.4 When the investigation assessed the instructor continuity metrics (Table 10 and Table 11) the occurrence SP, relative to other SPs on the same course, was found to have had less instructor changes than the course average. The investigation concluded that instructor continuity did not contribute to this accident.

2.12.5 It was reported to the investigation that the OTF is struggling to meet pilot production demands due to a lack of IPs. Although it was determined that the OTF has enough IP positions filled to meet the training demand (1.18.45), the extended training duration for the CH147F fleet indicates there are other factors at play. The difficulties experienced by the OTF to meet pilot production demands might be the result of IPs being assigned to higher priority taskings within 450 THS. The BFO & TAFO courses are considered priority 10 of 22 priorities at the unit (1.17.4), which is a known detriment of having an in-house OTF in lieu of an external OTU.

2.12.6 The investigation concluded that, in practice, the OTF was not allocated sufficient resources in terms of IPs and aircraft to complete the BFO and TAFO courses under the mandated timeline of the TEP. It is possible that the pressures on OTF were the result of pressures coming from higher headquarters (1 CAD) to perform Force Employment taskings; the exact impact/contribution from such taskings could not be determined by the investigation. As a first step, the TEP should be amended to secure such resources in support of the OTF. Paragraph 1.18.49 highlights differences in resources allocation within the TEPs of CH147F and the CH149 Cormorant.

MALA and RCAF Hangar Application

2.12.7 As detailed previously, the MALA was completed for this mission. The MA process was completed by an officer with delegated authority from the CO when the flying schedule was signed. The LA was completed by the AC (in this case the IP) electronically signing through Dispatch on the RCAF Hangar Application (1.17.10). The investigation determined that the occurrence AC was rigorous in completing the LA for each flight flown as AC, and that various aspects of the LA were discussed with the crew during the initial mission brief. It has also been determined that the RCAF Hangar Application allows a user to check a box indicating the LA worksheet as being completed without necessarily filling the form electronically. Hangar application specialists were unable to locate the electronic version of the LA worksheet, however, given that form 1017[92] did not record a score for the LA, it is likely that the worksheet was never entered electronically into the Hangar Application. No hard copy of the LA

[92] Tasking form in the Hangar application containing flight information for each mission.

worksheet was found at the unit. The investigation assessed that, given the IP's normal diligence in completing the LA, that the LA for this flight was likely completed manually and discarded.

2.12.8 The lowest illumination level assessed by the Met Tech for the duration of the mission was a corrected value of 0.54 mlx; however, the two SPs produced combined light tables indicating a value of 0.69 mlx for the mission. As reported previously (Annex K), the AC assessed the illumination level greater than 0.85 mlx. Although it is an accepted practice for each AC to do their own calculations of illumination, the investigation could not replicate a condition where the illumination was as high as 0.85 mlx. An illumination below 0.85 mlx would have raised the LA-score to five (5) which would have necessitated an approval by a flight supervisor who had delegated authority from the Commanding Officer (CO). The investigation determined that if approval had been sought for an LA score of five, it would have been granted.

NVG Operations

2.12.9 Reviewing how other fleets and nations incorporate illumination levels in their operations, the investigation has highlighted a few noticeable variations, which are repeated here:

- The FOM section on NVG Ops (deleted in Sep 22), which was based on Tactical Aviation (Tac Avn) experience documented the following:
  - At illumination of 1.5 millilux and below, local ambient in-flight light is required to permit precise navigation; and
  - Adjustment to mission profile and speed limits shall be made or flight cancelled following an appropriate in-flight assessment by the AC.
- Threshold to reach "High" risk on MALA varies from fleet to fleet (Table 8)
- The RAF:
  - "Red Illume conditions are defined as a period of the night where there are insufficient natural ambient light levels for NVG to provide sufficient references or contrast to allow unaided field landings and low-level flying techniques to be employed."
  - Light levels forecast below 10 millilux may create Red Illume conditions, requiring infrared radiation sources to illuminate the landing site.
  - The RAF use three NVG qualification levels. Based on their respective qualification levels, the crew are limited in how low they can fly on NVG.

2.12.10 When the FOM section on NVG Ops was in effect, 1.5 mlx was the threshold to require additional ambient light for navigation, and necessitated adjustment to mission profile and speed under these conditions. When the FOM section on NVG Ops was deleted in Sep 22, the Tac Avn community (CH146 Griffon & CH147F Chinook) incorporated a threshold of 0.85 mlx to trigger a "High" risk in the MALAs of both fleets. There is no documentation to support the lowering of the illumination threshold, however, it has been reported that the change was based on experience. Considering the NVGs in use have not been upgraded it is difficult to understand what might support such an approach. Illumination level played a significant part in this accident (contributed to the creation of the Black Hole Effect) and as a result, the investigation considers that the FOM should re-introduce high-level guidance for NVG operations.

2.12.11 Following the accident, 450 THS issued two AIFs that targeted a higher level of safety during night operations (AIFs 23-19 and 23-20, see Annex I). Had these measures been in place on the day of the accident, the accident could have been prevented. The measures are deemed valuable enough to be implemented permanently in the CH147F SMM, and other rotary-wing RCAF fleets as appropriate.

AEROMEDICAL TRAINING

2.12.12 Within AMT, Hypoxia Recognition Training can sometimes overshadow the rest of the program due to its profound importance in aviation and its significant resource demand of delivering the training. As such, topics related to spatial disorientation and NVG use, that are of great importance to rotary-wing operations, are more easily deprioritized in general. These are areas that could benefit greatly from modernization and amplification to increase awareness and knowledge within the rotary-wing community.

2.12.13 The Bárány chair is the only training tool used by the RCAF; it is an effective introduction to vestibular limitations but lacks much of the value seen in the more refined and advanced tools. High-fidelity spatial disorientation trainers allow for a more realistic cockpit environment, provide flight visuals, flight parameter modulation, fixed-wing & rotary-wing specific profiles, auditory stimulus and distractions, vestibular stimulation through visual matched motion cueing and more. All these features are used for spatial disorientation training by many of our allied counterparts such as RAAF, RAF, Netherlands, USAF, US Army, US Navy, etc., which may result in the generation of safer pilots with enhanced management skills.

2.12.14 There remains some ambiguity regarding the completeness of the NVG program delivery due to exact roles and responsibilities not being clearly defined. This training has been largely divested from the Canadian Forces School of Survival and Aeromedical Training (CFSSAT) creating expectations set upon the units to conduct in-house, platform specific training as outlined by their own training program. The RCAF would, in the past, send members to participate in USAF provided NVG Ground training but foreign participants are no longer permitted to attend this course. This gap has been managed by having Aviation Physiology Technicians teach the foundational components with a brief hands-on period. Of note, this relies on the passing of information from legacy instructors to younger generations and may not meet the standard for qualified instruction based on NATO Allied AeroMedical Publication AAMedP 1.2 in that “A qualified NVG ground instructor is an individual who has graduated from a NVG ground course acceptable to his or her national authority”. The investigation was not able to find which ground course was deemed acceptable to qualify an RCAF NVG ground instructor. Similarly, the RCAF has no clear standard for the NVG flight instruction occurring on DND aircraft.

2.12.15 The RCAF QS for AMT, as supported by 1 CAD order 5-301, states that "all non-helicopter aircrew shall complete Hypoxia Recognition Training (HRT) and physiological simulator recertification every ten years" which allows for this requirement to only apply to non-helicopter aircrew; consequently after initial AMT, rotary-wing crew receive no formal refresher on spatial disorientation beyond the digital package required as distance learning every five years. The investigation considers that a more formal in-person, helicopter specific AMT recertification every 10 years (or every five years to follow international interoperability doctrine) for rotary-wing crews would improve spatial disorientation awareness.

2.13 EMERGENCY RESPONSE

2.13.1 This section will analyse the emergency response and the various ERPs from an organizational perspective. The investigation acknowledges that all parties involved in the emergency response made things work in the end, but the investigation highlighted a few areas for improvement.

FIRST RESPONDERS

2.13.2 Garrison Petawawa is next to the Ottawa River, which is a large body of water. Knowing that the accident happened on the river, the first responders divided into two distinct teams; one team from the Crash Fire Hall going to Wegner Point and the other team from the Garrison Fire Hall going to Jubilee Marina (approximately five kilometres away from the Garrison Fire Hall) to launch the Zodiac boat, since there is no boat launch site on the Garrison grounds. The team at Wegner Point arrived eight minutes after the crash alarm bell was activated (Table 3) but had no watercraft and had to revert to canoes that were coincidentally found nearby. Given the short distance between the Crash Fire Hall and Wegner Point (approximately 600 m), eight minutes seems like a long time, however, initial confusion as to the exact location of the accident may account for part of this delay. A lack of a PA System at the Crash Fire Hall (1.15.7) contributed to this confusion by adding delays in the passage of information between the two fire halls and potentially introducing errors as the message was being relayed. The PA system is essential to pass information to first responders while they are getting ready to respond. Garrison Petawawa should implement a PA system that is functional in both the Garrison Fire Hall and Crash Fire Hall.

2.13.3 The Zodiac boat arrived at the accident site 22 minutes after the first emergency response team arrived at Wegner Point (Table 3). The delay was caused by the team having to drive five kilometres to Jubilee Marina and then ride the launched Zodiac approximately five kilometres to the accident site. The river near the Jubilee Marina has many locations where the depth is shallow, resulting in slower progress by boat. The investigation considered this 22-minute delay to be excessive, especially given that Wegner Point is located close to the Crash Fire Hall. To minimize response delays for accidents on the Ottawa River, Garrison Petawawa should find a method to use Wegner Point as an emergency launch site for their watercraft.

2.13.4 The Garrison Fire Hall Zodiac boat has a maximum capacity of nine personnel. Considering that the Zodiac crew would normally consist of two personnel (one driver and one rescuer), this leaves room for seven survivors. The CH147F maximum occupancy of 37 personnel (1.6.1) would very quickly exceed the current Zodiac capacity. The investigation recognizes that the CH147F does not always fly at the maximum occupancy, but this does not alleviate the requirement for the Garrison to be ready to respond to a worst-case scenario. The following should be considered:

- Additional and/or larger watercraft to rescue 37 survivors;
- Watercrafts equipped with night search capability such as searchlights;
- Deployable rafts (possibly inflatable) that could be towed by the watercrafts for the survivors to use as flotation in cases where the number of survivors would exceed the Zodiac capacity. This way the survivors would have a means to stay afloat while the Zodiac is making round trips to the beach. It would also provide a means for survivors to get out of the water, reducing the risk of hypothermia; and
- Review first responders' inventory to assess if both Fire Halls are properly equipped to respond to emergency situations across all Garrison operating environments (such as training areas not accessible by road, or an island located in the Ottawa River).

2.13.5 The investigation noted a few challenges in the emergency response that were related to different cultural issues between the CA and the RCAF. By virtue of their operating environments and history, the CA and RCAF have developed differing approaches to SOPs and even unique vocabularies and slang. A word spoken by an RCAF member may not convey the same meaning to a member of the CA. This presents a challenge when required to work in a joint operation, as any response to an aeronautical emergency at Garrison Petawawa would be a joint response. The urgency of such a response does not allow for an educational period between the organizations. To be optimally effective, seamless integration must occur from the beginning. At the time of this report, the Canadian Joint Operations Command was already working on developing a contingency plan (CONPLAN HERMES) which is aimed at achieving better integration between all parties and ensuring maximum efficiency when responding to aircraft accidents. CONPLAN HERMES should continue to be developed and periodically exercised once completed.

OSCER DUTIES

2.13.6 OSCER is a key position of any emergency response as they "control" the on-scene emergency response. They are an extension of the Chain of Command (CoC), controlling the on-site elements of their response. The span of command & control needing to be managed can grow very rapidly when dealing with large scale accidents, as was the case for the *Hammer 31* accident. The OSCER duties were carried out by a Captain and a Warrant-Officer, alternating to cover the 24/7 response (i.e. day and night). The response to *Hammer 31* accident involved a large number of people, at times in excess of one hundred, coming from multiple organizations. This represents a monumental task for a single person coordinating as OSCER. OSCER should be provided with a direct, scalable support team to be able to delegate various tasks as required to avoid being overloaded.

2.13.7 Another challenge to the response was that the OSCER duty vehicle was not available as it was off base for repairs. Since there was no alternate OSCER duty vehicle or any sort of alternate plan, OSCER did not have the resources required to conduct their duties such as radios, checklists, and maps. These are normally contained in the OSCER duty vehicle. The OSCER vehicle is typically clearly labelled as "OSC" or "OSCER" and serves as the central command post while on scene. One of the biggest challenges on Wegner Point was communication. The area does not have effective cellular coverage, and having no radios, some responders reverted to using Facebook Messenger for communication, which is not an ideal situation to transmit sensitive information. To alleviate this situation, it is recommended that alternative plans be put in place to provide OSCER with the necessary resources to conduct their duties when the primary OSCER vehicle is unavailable for use.

ERP

2.13.8 There were three ERPs the investigation looked at: the 4 CDSB ERP, the 1 Wing ERP, and the 450 THS CRP. It was found that 1 Wing no longer has an ERP, because of its dispersed nature and the fact that no aviation assets from the Wing are stationed in Kingston where 1 Wing HQ is located. This is contrary to the AIM which mandates a formation level ERP. (1.15.6). The ERP is an important document defining the roles and responsibilities of key personnel, both from a CoC as well as a Flight Safety perspective. The lack of a 1 Wing ERP creates a gap in the CoC between stakeholders, in this case 450 THS and 1 CAD HQ, but also leaves all the responding responsibilities to the local base, in this case 4 CDSB. Recognizing that a lot of the responsibilities would fall to the local base CoC, 1 Wing needs to establish communications protocol to ensure adequate liaison between the local base and 1 CAD. It is recommended that 1 Wing HQ reinstate their ERP. The ERP should be tailored to the realities that come with their subordinate Squadrons being lodger units on CA bases.

2.13.9 The investigation found conflicting evidence as to the last time the 4 CDSB ERP had been exercised. Some evidence suggested that a tabletop exercise had been conducted in the Fall of 2022, while other evidence suggested that it had been several years since the last exercise. A review of the 4 CDSB ERP revealed that the phone number for reporting an aircraft accident was listed incorrectly. This suggests that either the ERP had not been exercised as per the direction in the AIM, or if it had, the exercise was only conducted superficially as an in-depth exercise would have likely uncovered the erroneous number. 4 CDSB completed an After Action Review of this accident and made over 100 recommendations. 4 CDSB needs to review their ERP and amend as required, including the lessons learned from *Hammer 31*'s accident[93]. Following the

[93] After Action Review (AAR) of CH147F Chinook Crash at Garrison Petawawa on 20 Jun 23, 3 Sep 23

review, 4 CDSB should conduct a tabletop exercise involving all key stakeholders, followed by a large-scale practical Crash Exercise within 12 months.

2.13.10 With respect to the WFSO and BFSO positions, although these positions have somewhat similar roles and responsibilities, each are accountable to their respective commander (i.e. 4 CDSB or 1 Wing). The investigation believes that such double assignments of Flight Safety Officer (FSO) duties run the risk of very quickly overtasking the individual and/or paying a disservice to one of the organizations which would have to manage a major accident situation without ready access to their respective FSO. If 1 Wing and/or 4 CDSB want or need to double hat a given individual with both FSO positions, they should harmonize their respective ERP to account for that. They also would have to make sure they have deputy FSOs in place to account for their respective Flight Safety responsibilities if/when the WFSO/BFSO is occupied with the other organization's duties.

2.14 Survivability Aspects

Aircraft Emergency Exit Lights

2.14.1 As mentioned previously (1.15.18), the FEs did not have usable interior cabin illumination post impact, delaying their egress. The investigation considered four possible scenarios to explain the lack of emergency exit lighting in the cabin:

a. the EMER EXIT switch on the INTR LTG panel of the overhead panel was not placed to "ARM", in which case the lights would not turn on automatically post impact;

b. the brightness of the emergency exit lights was too dim for the FE to see the light;

c. there was a system malfunction; or

d. the EMER EXIT switch moved from the ARM to the DISARM position during the breakup sequence.

2.14.2 Each scenario was assessed, in turn. Scenario (a): Considering the PRE-START CHECK covers the INTR LTG setting, it would have been performed at the start of the mission with the first SP; it is possible the switch was put in the "ARM" position, but neither CVR nor FDR could confirm this. Scenario (b): Based on the reports from the fuselage recovery divers, it is known that the Ottawa River in this area has poor visibility, which could have prevented the FEs from perceiving the light from the emergency lights that are known to provide poor illumination (1.16.7). Scenario (c): The investigation found no reason the emergency lights themselves would not have functioned normally assuming their batteries held sufficient charge prior to the impact. The loss of aircraft battery (1.12.2) and/or damage incurred to the lighting circuit at the front of the aircraft at the time of impact would have activated the emergency lighting system; a system malfunction is considered unlikely. Scenario (d): Although this would have prevented the aircraft emergency exit lighting from activating at the time of impact, the investigation could not validate this scenario. The investigation could not definitively determine the reason for lack of illumination in the cabin.

FUNCTIONING OF ALSE

Eagle Vest CRR

2.14.3 During the accident, both FEs used the safety-gate snap hook in the back of their vest to release their monkey tails; however, one of the FEs unsuccessfully attempted to use the CRR (1.15.47). During the post accident inspection of the ALSE equipment, the Eagle Vest that malfunctioned was found with slack in the anchor strap which may have contributed to the failed activation attempt. To recreate the malfunction, the anchor strap of the CRR was deliberately loosened for four test participants. Participants executed the release procedure, resulting in the respective CRR systems functioning as designed. Two possible scenarios could explain the unsuccessful attempt to use the CRR: (1) the adjustment of the vest was too loose, preventing the snap fastener from releasing the CRR; or (2) an improper motion was applied to release of the snap fastener, in that a downward as opposed to outward and upward movement was carried out. Such improper motion could have been the result of the FE being disoriented while underwater.

2.14.4 The investigation found that some crewmembers were not having their vest re-adjusted after every seasonal change (i.e. winter to summer, summer to winter). That particular FE's vest was last adjusted on 27 Apr 22, which means that their vest had missed two seasonal fittings; one in the Fall of 2022 and another in the Spring of 2023) (Table 5). It was reported to the investigation that seasonal adjustment was not available to crewmembers due to the staffing issues in the ALSE shop (1.17.5). Considering that the vest had last been adjusted in the Spring of 2022, it would have been fitted for summer season clothing; however, since the vest had also been used in this configuration during winter operations, it was likely that the summer adjustment had been too loose, which could explain the malfunction. Missing seasonal adjustments may result in additional looseness (or tightness) that could impact ALSE operation.

2.14.5 A review of the yearly egress training requirements revealed that the activation of the CRR by FEs is not mandated, and consequently it is not exercised at all units. One possible explanation is the requirement for re-rigging by a qualified ALSE technician after each CRR use (1.15.50). In situations where the monkey tail is under tension, the CRR might be the only method that would allow the FE to release it, so it is important for the FE to be familiar with the multiple motions and forces necessary to activate the CRR. As the CRR is never used under normal conditions, yearly egress training is the only opportunity for FEs to familiarize themselves with the system. The investigation believes that the added benefits of realistic training to develop "muscle memory" in an emergency outweighs the added workload of re-rigging the harness and helps to mitigate the risks associated with an egress scenario. Furthermore, some units have been asking the users to activate the CRR of their vest when their equipment was due for the 180-day inspection; this is considered good practice to re-enforce "muscle memory".

HGU-56/P-CF Aircrew Helmet and DTLP Binding.

2.14.6 Other than one pilot that was wearing the LP/SV, the crew members were wearing an Eagle Vest with the DTLP removed. The RCAF FOM 4.2.2.9 states that a survival vest, LP/SV, and EBS shall be worn as per mission requirements. The two orders that pertain to mission requirements are: FOM 2.4.9.2 – CH147F Extended Overwater Operations and FOM 3.6.2.24 – RUET/EBS Training which covers overwater operations (Annex H). Crews flying locally out of Petawawa do not meet the criteria for extended overwater operations since they never fly 10 minutes or more from shore. As *Hammer 31* never intended to fly below safe single engine speed over water, the requirements in FOM 3.6.2.24 did not apply. This meant that the crew was permitted, within the current orders, to remove their DTLP given their mission profile.

2.14.7 Although permitted by current orders, the removal of the DTLP by crew members had been a common practice due to binding issues between the helmet and the DTLP. The binding issue was not only considered a comfort problem, but a hindrance to operations as well because it limited head movement. The binding issue between the HGU-56/P-CF and the Eagle Vest was first raised in a LATEF report dating back to 2011 (1.15.40). The investigation could not find any Unsatisfactory Condition Reports (UCR) or RARMs on the subject. The only documents that could be found were two SOCDs, one written by 427 SOAS and the other by 450 THS (1.15.41).The investigation concluded that the binding was a known issue at the unit level but not at the operational and strategic levels; likely because the issue never reached 1 CAD HQ (through SOCD, UCR, or even a Flight Safety occurrence). The investigation was not able to determine why the staffing process was interrupted. This situation precluded Operational Airworthiness (OA) staff from risk assessing the situation and thus the deficiency was not addressed nor mitigated.

2.14.8 The AIA issued an immediate preventive measure on 14 Nov 23 to highlight the situation, which resulted in RARM ALSE-2023-004 being issued, documenting the risk of binding between the Eagle Vest and the DTLP. The risk was assessed at EXTREMELY HIGH and 1 Wing HQ immediately issued a direction to cease flying operations with the DTLP attached to the Eagle Vest, bringing the mitigated risk level to ALOS. (1.15.39).

ROTARY-WING UNDERWATER ESCAPE TRAINING (RUET)

2.14.9 The investigation team surveyed 10 different Allied Nations conducting military helicopter operations and found that currency requirements in which crews must return for refresher RUET/EBS training varied between one and six years; only one nation mandates a six-year cycle. At the time of the accident, RCAF tactical aviation crews were mandated to undergo RUET/EBS refresher training once every 10 years. This discrepancy in RUET/EBS refresher training timelines may lead to RCAF tactical aviation crews being less proficient and facing greater risk when responding to a ditching scenario. To remain consistent with other aviation communities (SAR & Maritime) as well as other nations, a maximum recurrent RUET training cycle of five years is recommended for the Tactical Aviation community.

2.14.10 Since the accident, 1 CAD HQ amended orders (CADO 5-306) mandating that Tactical Aviation aircrew undergo RUET/EBS training once every five years.

2.15 SUMMARY

2.15.1 As in most accidents, there were multiple elements that contributed to *Hammer 31*'s accident.

2.15.2 As the IP initiated the left turn, the bank angle was initially brought to 36 degrees. The aircraft remained at that bank angle for approximately seven seconds, during which time the SP was handed the controls. During these seven seconds, the crew of *Hammer 31* did not apply enough thrust or set the proper attitude to maintain a constant altitude. Over this 7-second period, the rate of descent slowly increased, seemingly without the crew being aware. Following this 7-second period where the bank angle was approximately 36 degrees, the bank angle reduced, and the aircraft maintained a constant rate of descent of approximately 1000 fpm for the last 19 seconds of the flight.

2.15.3 At the start of the 19 seconds where the flight was at a constant rate of descent, it is likely that the crew were unaware of their exact rate of descent and may have believed they were at a relatively constant altitude, suffering from spatial disorientation. The subsequent manual thrust reductions, resulting in reduced engine torque values from 59% to 18%, would indicate an intent to initiate a descent; however, the conditions that night were perfect for the creation of a Black Hole Effect which would have rendered it much more difficult to use external visual cues to assess height and rate of descent while using NVG. The investigation concluded that in an environment with multiple different, yet concurrent tasks, both pilots likely became task saturated with their own separate duties, to the detriment of monitoring altitude and/or rate of descent. Finally, the investigation concluded that the RADALT low altitude audio warning was likely cancelled reflexively by one of the pilots to focus on giving or receiving navigational instructions, and task saturation prevented further actions. Although one of the FEs heard the RADALT low altitude audio warning, none of the potential scenarios analysed, reference FE actions, would have prevented the accident during the final moments before impact.

2.15.4 As the aircraft was deemed to be serviceable, and it appears that none of the crew members realized the height and/or rate of descent of the aircraft before impact, this meets the classic definition of CFIT (1.13.8).

3. CONCLUSION

3.1 FINDINGS

3.1.1 The aircraft was serviceable, and the crew was current and qualified for the mission. [1.5.1, 1.6.4, 1.16.13, 2.1.1, 2.7.5]

3.1.2 During the seven seconds when the bank angle was 36 degrees, the crew of *Hammer 31* did not apply sufficient thrust or set the proper attitude to maintain level flight, resulting in a slow but increasing rate of descent. [2.2.2]

3.1.3 The initiation of the descent at the start of the turn, while the bank angle was 36 degrees, was possibly unintentional. [2.3.3]

3.1.4 The crew would not have been able to depend solely on their vestibular system to detect the acceleration forces, resulting in an unidentified increase in rate of descent. [2.4.1]

3.1.5 Following the 7-second period of increasing descent rate, a constant vertical speed of 1000 fpm (+/- 200 fpm) was maintained for the last 19 seconds of the flight. [2.4.2]

3.1.6 The accident leg was the first and only time *Hammer 31* flew over the river that night (away from shore). [2.5.1]

3.1.7 The crew did not use any of the SMM recommended mitigating measures for overwater flight: (a) follow shorelines of bodies of water, (b) use Native modes, and (c) increase height above the water. [1.18.62]

3.1.8 The environmental conditions, both the illumination level and the calm winds, created a Black Hole Effect over the Ottawa River. [2.5.1]

3.1.9 As a result of the Black Hole Effect, the ability to use visual cues from the crew's NVG was negated, leaving only flight instruments to monitor their descent rate. [2.5.2]

3.1.10 During the last 19 seconds of flight, the descent was likely intentional. [2.6.2]

3.1.11 The call "*Moving Down*" may not have been necessary under the circumstances of this leg. [2.3.2a].

3.1.12 The call "Moving Down" was not made as mandated by the SMM. [2.7.2]

3.1.13 When the controls were passed from the IP to the SP, the aircraft was in a descent rate of 300 fpm. [1.11.3]

3.1.14 When the controls were passed from the IP to the SP, there was no mention to indicate the aircraft had initiated the descent. [2.3.2a]

3.1.15 The altimeter, vertical speed indicator and RADALT were not effectively monitored by the pilots, and consequently were not aware of the aircraft's rate of descent and/or altitude. [2.7.2]

3.1.16 Neither FE was aware of the aircraft rate of descent or aircraft height. [2.7.3]

3.1.17 The crew members of *Hammer 31* were unaware of the imminent danger from the proximity of the water.[2.7.3, 2.8.1, 2.8.3]

3.1.18 It is likely that time spent looking inside the cockpit, combined with the Black Hole Effect, caused the FO/SP/PF to lose situational awareness. [2.9.2]

3.1.19 The FO/SP/PF likely lowered the thrust with the intent of reducing the airspeed. [2.9.3]

3.1.20 The FO/SP/PF was likely task saturated with their attention channelized on airspeed to the detriment of monitoring altitude and/or rate of descent. [2.9.3]

3.1.21 The AC/IP/PM was likely task saturated with their attention channelized on PM duties (*Before Landing Check* and navigation) to the detriment of monitoring altitude and/or rate of descent. [2.9.4]

3.1.22 The AC/IP may not have been as alert during the second half of the mission. [2.9.5]

3.1.23 Multiple factors were present, which likely led to unrecognized spatial disorientation of all crew members of *Hammer 31*, resulting in continued descent until water impact. [2.10.2, 2.10.3]

3.1.24 The RADALT low altitude audio warning was cancelled by one of the pilots, likely reflexively without processing the implications. [2.11.3]

3.1.25 Knowing that the RADALT warning sounded 7.4 seconds before impact, there was theoretically sufficient time for the FO/SP/PF to react and avoid impact. [2.11.8]

3.1.26 Task saturation and/or spatial disorientation within the crew is likely why the RADALT warning was not acknowledged and responded to appropriately. [2.11.8, 3.1.23]

3.1.27 The RADALT setting was only verbalized once despite being required five separate times following the hot turn. [2.11.11]

3.1.28 Mission tempo may have forced the crew to compress the checklists leading to missed checks. [2.11.11]

3.1.29 At a height of 20 ft AGL, a more assertive call by the FE would not have resulted in recovering the aircraft prior to impact. [2.11.12, 2.11.14]

3.1.30 Core FG (Initial Training), which includes BFO & TAFO courses, is priority 3D. In a simple ranking of the 22 priorities, priority 3D falls at number 10. [1.17.4]

3.1.31 BFO 2102 and TAFO 2202 took 2.6 times more time than authorized by the TEP. [1.18.36]

3.1.32 The investigation concluded that, in practice, the OTF was not allocated sufficient resources in terms of IPs and aircraft, to complete the BFO and TAFO courses under the mandated timeline of the TEP. [2.12.6]

3.1.33 The long breaks in training likely eroded the FO/SP's proficiency. [2.12.3]

3.1.34 The investigation determined that the FO/SP's difficulties in the BFO basic night phase were not related to the accident flight scenario and concluded that these were not causal. [1.5.9]

3.1.35 The TEP found no specific mention of training/exposure requirement with respect to the Black Hole Effect. [1.18.50]

3.1.36 The investigation concluded that instructor continuity did not contribute to this accident. [2.12.4]

3.1.37 The LA worksheet for *Hammer 31*'s mission could not be recovered; the investigation generated the LA worksheet based on all information available. [1.17.10]

3.1.38 The RCAF Hangar Application allows the user to check a box indicating the LA worksheet as being completed without necessarily filling the form electronically. [2.12.7]

3.1.39 An illumination below 0.85 mlx would have raised the LA score to five (5) which would have necessitated an approval by a flight supervisor. The investigation determined that if approval had been sought for an LA score of five, it would have been granted. [2.12.8]

3.1.40 There was a variation in the illumination assessment, ranging from 0.54 mlx to 0.85 mlx. [2.12.8]

3.1.41 When the FOM section on NVG Ops was in effect, 1.5 mlx was the threshold to trigger additional mitigating measures. When the FOM section on NVG Ops was deleted in Sep 22, the Tac Avn community (CH146 Griffon & CH147F Chinook) incorporated a threshold of 0.85 mlx to trigger a "High" risk in the MALAs of both fleets. [2.12.10]

3.1.42 AIFs 23-19 and 23-20 (Annex I) were introduced after the accident to increase safety margins. [2.12.11]

3.1.43 Topics on SD and NVG may not receive sufficient time allocation and emphasis during aeromedical training. [2.12.12]

3.1.44 The RCAF does not have a high-fidelity spatial disorientation trainer, which is used by most of its allies. [2.12.13]

3.1.45 There is no lead agency to manage the RCAF NVG training. [2.12.14]

3.1.46 NVG ground instructor qualification may not meet the intent of the NATO agreement; consequently, the RCAF training construct may lead to instructor knowledge fade. [2.12.14]

3.1.47 The RCAF has no clear standard for the NVG ground and flight instruction occurring on DND aircraft. [2.12.14]

3.1.48 Rotary-wing aircrew complete their initial AMT course at CFSSAT and then are only required to complete the distance learning recertification every five years. [2.12.15]

3.1.49 The lack of a PA system that simultaneously broadcasts in both the Garrison Fire Hall and Crash Fire Hall contributed to delays in the passage of information between the two fire halls and potentially introducing errors as the message was being relayed. [1.15.7, 2.13.2]

3.1.50 Garrison Petawawa is next to the Ottawa River, necessitating frequent flights over water. [2.13.2]

3.1.51 The Zodiac boat arrived on-scene 22 minutes after the first emergency response team arrived at Wegner Point. [2.13.3]

3.1.52 The Garrison Petawawa Fire Hall Zodiac boat has a capacity of nine personnel, which would limit its ability to recover personnel in the case of a CH147F accident, when at or near maximum occupancy. [2.13.4]

3.1.53 The span of control required of the single individual acting as OSCER during the response was too large. [2.13.6]

3.1.54 A duty vehicle was not available to OSCER at the time of the accident. [2.13.7]

3.1.55 Communications at Wegner Point does not have effective cellular coverage, and having no available radios for use, some responders reverted to using Facebook Messenger for communication. [2.13.7]

3.1.56 Since May 22, the officer holding the position of 1 Wing WFSO was also double-hatted and held the position of 4 CDSB BFSO. [1.17.11]

3.1.57 1 Wing HQ did not have an ERP at the time of accident. [2.13.8]

3.1.58 The 4 CDSB ERP was not effectively exercised prior to the accident. [2.13.9]

3.1.59 4 CDSB completed an After Action Review of this accident and made over 100 recommendations. [2.13.9]

3.1.60 The FEs' egress from the aircraft was hampered by a lack of illumination within the cabin. [1.15.18]

3.1.61 The EMER EXIT switch on the INTR LTG panel was discovered in the DISARM position when the aircraft was recovered. [1.16.4]

3.1.62 The serviceability of the inertia switch assembly immediately prior to impact could not be determined based on post-accident condition. [1.16.4]

3.1.63 QETE testing found a number of issues with the emergency lights and batteries, some of which might have pre-existed prior to the accident. [1.16.5]

3.1.64 All three lights were reassembled with the original batteries and were found functional, producing a bright illumination for over 20 minutes. [1.16.5]

3.1.65 To perform tests on an emergency light from supply, the new spare batteries had to be reconditioned several times and attained only half of their nominal charge capacity. [1.16.6]

3.1.66 The investigation could not definitively determine the reason for lack of illumination in the cabin. [2.14.2]

3.1.67 The OEM modification for HEELS has remained unfunded since 2019. [1.16.7]

3.1.68 One of the FEs unsuccessfully attempted to use the CRR system on the Eagle Vest. [2.14.3]

3.1.69 Two possible scenarios could explain the unsuccessful attempt to use the CRR: (1) the adjustment of the vest was too loose; or (2) an improper motion was applied to activate the CRR system. [2.14.3]

3.1.70 Missing seasonal adjustments may result in additional looseness (or tightness) that could impact ALSE operation. [2.14.4]

3.1.71 Use of the CRR is not mandated in yearly egress training, contributing to a lack of familiarity with the system. [2.14.5]

3.1.72 Other than one pilot that was wearing the LP/SV, the crew members were wearing an Eagle Vest with the DTLP removed. [2.14.6]

3.1.73 The binding issue between the HGU-56/P-CF and the Eagle Vest was first raised in a LATEF report in 2011. [2.14.7]

3.1.74 The issue of helmet binding was not known at the operational or strategic levels, precluding OA staff from taking mitigating actions. [2.14.7]

3.1.75 An ALSE RARM was issued, documenting the risk of binding between the Eagle Vest and the DTLP. The risk was assessed at EXTREMELY HIGH and 1 Wing

HQ immediately issued a direction to cease flying operations with the DTLP attached to the Eagle Vest, bringing the mitigated risk level to ALOS. [2.14.8]

3.1.76 At the time of the accident, RCAF tactical aviation crews were mandated to undergo RUET/EBS refresher training between five to 10 years. [Table 6]

3.1.77 The CH147F TEP is inconsistent throughout the document in terms of review trips counting as non-course time, the RCAF rotary-wing fleet TEPs are similarly inconsistent in this regard. [1.18.41]

3.1.78 RCAF helicopter fleets' RADALT procedures are dependent on the flight profile being flown and contain no standard procedures for transitioning from a high flight profile to a low flight profile. Such procedures would enhance safety of flight in the transition phase. [2.11.15]

3.2 CAUSE FACTORS

ACTIVE CAUSE FACTORS

3.2.1 The environmental conditions, in that the illumination level and the calm winds, created a Black Hole Effect over the Ottawa River. [3.1.8]

3.2.2 During the seven seconds when the bank angle was 36 degrees, the technique used by the crew of *Hammer 31* resulted in insufficient thrust to maintain level flight, causing the slow but increasing rate of descent. [3.1.2]

3.2.3 The crew of *Hammer 31* could not depend on their vestibular system to detect the slow increase in rate of descent. [3.1.4]

3.2.4 Multiple factors were present which likely led to unrecognized spatial disorientation of all crew members of *Hammer 31,* resulting in a continued descent until water impact [3.1.23]

3.2.5 The altimeter, vertical speed indicator and RADALT were not effectively monitored by the crew. [3.1.13]

LATENT CAUSE FACTORS

3.2.6 The AC/IP may not have been as alert during the second half of the mission. [3.1.22]

3.2.7 The FO/SP/PF was task saturated with their attention likely channelized on airspeed to the detriment of monitoring altitude and/or rate of descent. [3.1.20]

3.2.8 The AC/IP/PM was task saturated likely causing their attention to be channelized on PM duties to the detriment of monitoring altitude and/or rate of descent. [3.1.21]

3.2.9 Mission tempo may have forced the pilots to abbreviate the completion of checklist items, leading to missed checks. [3.1.28]

3.2.10 Crew task saturation and/or spatial disorientation likely led to the lack of acknowledgment following the RADALT warning [3.1.26]

3.2.11 The long breaks in training likely eroded the FO/SP's proficiency. [3.1.33]

3.2.12 The OTF was not allocated sufficient resources in terms of IPs and aircraft to complete the BFO and TAFO courses under the mandated timeline of the TEP. [3.1.32]

4. PREVENTIVE MEASURES

4.1 Preventive Measures Taken

4.1.1 450 THS issued AIF 23-18 mandating LP and EBS use for over water ops, AIF 23-19 mandating 100 ft minimum height over water at night when illumination <1.5mlx, and AIF 23-20 mandating use of Native mode DAFCS in certain over water conditions. [1.15.45, 3.1.42]

4.1.2 450 THS re-instated sufficient staffing levels in the ALSE section, to ensure proper maintenance standards and record keeping. [1.17.5]

4.1.3 RARM ALSE-2023-004 was issued, documenting the risk of binding between the Eagle Vest and the DTLP. The risk was assessed at EXTREMELY HIGH. [3.1.75]

4.1.4 1 Wing HQ issued direction to cease flying operations with the DTLP attached to the Eagle Vest, bringing the mitigated risk level to ALOS. [3.1.75]

4.1.5 Lighting levels at the Canadian Special Operations Regiment compound (located near the FATO) was reduced by approximately 50%. This has reduced the effect of light pollution around the airfield.

4.1.6 1 CAD HQ amended orders (CADO 5-306) mandating that Tactical Aviation aircrew undergo RUET/EBS training once every five years. [3.1.76]

4.2 Preventive Measures Recommended

4.2.1 SSO Tac Avn to amend the CH147F SMM and implement the following changes:

a. Formalize the use of Native modes DAFCS similar to that published in AIF 23-20 (Annex I). [3.2.1, 3.2.3]

b. Implement the measures restricting minimum altitude as stated in AIFs 23-19, (Annex I). [3.2.1]

c. To train “muscle-memory” and take appropriate action every time the RADALT tone is heard (even if verbal only), it is recommended that the SMM note related to approach be removed. Specifically, the note indicating that verbal acknowledgment of audio alert activation is “Not required when RADALT audio is expected on approach.” [3.1.26]

d. Formalize the current best practice: when the RADALT tone is not acknowledged by the PF, the command “*RADALT – Move Up*” is called by another crew member. Considering that the aircraft would then already be at least 20% lower than the minimum/planned altitude, the call should be an authoritative command calling for immediate and unquestionable action by the

PF (e.g. similar to a Traffic Collision Avoidance System Resolution Advisory). [2.11.14]

4.2.2 SSO Tac Avn / TASET to review the amount and duration of required verbalized checks conducted by Tactical Aviation aircrew, with a consideration to mandate verbalization of RADALT bug setting every time it is called for in a checklist; and implement changes in appropriate publications. [3.2.9]

4.2.3 450 THS to amend the TEP and allocate the OTF sufficient resources in terms of IPs and aircraft, including a dedicated aircraft, to complete the BFO and TAFO courses under the mandated timeline of the TEP; ensuring course delays are minimized during this critical phase of training. Additionally, evaluate TEP content to ensure adequate training is conducted in Black Hole Effect conditions, either unaided night or low mlx in the Flight Simulator. [3.2.12, 3.1.31, 3.1.35]

4.2.4 1 CAD Chief of Staff to amend the FOM and re-introduce high-level guidance for NVG operations; a minimum illumination threshold (e.g. 1.5 mlx) should be determined where mitigation measures are to be implemented. [3.2.1]

4.2.5 1 CAD Chief of Staff to amend the FOM to include high-level guidance for positive transfer of flight controls/controllers that includes the verbalization of heading, altitude, airspeed, climb/descent and level of automation affecting the flight vector of the aircraft. [3.2.4, 3.1.13, 3.1.14]

4.2.6 1 CAD Dir Flt Rdns to review 1 CAD fleet MALA following FOM amendment implemented at PM 4.2.4. [3.2.1]

4.2.7 2 CAD Dir AF Trg to review 2 CAD fleet MALA following FOM amendment implemented at PM 4.2.4. [3.2.1]

4.2.8 1 CAD Dir Fleet Rdns to implement the measures stated in AIFs 23-19 and 23-20 (Annex I) on other 1 CAD RCAF rotary-wing fleets as appropriate. [3.2.1, 3.2.3]

4.2.9 2 CAD Director of Air Force Training (Dir AF Trg) to implement the measures stated in AIF 23 20 (Annex I) on other 2 CAD RCAF rotary-wing fleets as appropriate. [3.2.1, 3.2.3]

4.3 Other Safety Measures Recommended

4.3.1 1 CAD Dir Fleet Rdns to review all RCAF fleets' SMMs with a view to harmonize all RADALT setting procedures and to include clear directions on how to manage RADALT low altitude settings in the transition between flight profiles, mainly from high to low flight profiles. [3.1.78]

4.3.2 Director RCAF Digital HUB (the technical authority for the RCAF Dispatch application) is to review the quarantine function of the application to ensure the information is safeguarded and/or cannot be tampered with in support of future DFS investigations. In addition, the application is to be amended so that the LA worksheet must be filled before indicating it is completed. [3.1.37, 3.1.38]

4.3.3 Directorate of Air Domain Development to prioritize acquisition and implementation of a high-fidelity Spatial Disorientation Trainer. [3.1.43, 3.1.44]

4.3.4 2 CAD Dir Air Force Training to assign/develop NVG SME, who would develop Qualification Standard (QS) and currency requirements for NVD ground training (in AMT at CFSSAT) of both instructors and aircrew throughout the RCAF. This work is to be carried out in collaboration with Health Services aeromedical advisors and shall meet the requirements of NATO Standard AAMedP-1.21 where applicable. [3.1.45, 3.1.46, 3.1.47]

4.3.5 1 CAD Dir Fleet Rdns to assign/develop NVG SME, who would develop Qualification Standard (QS) and currency requirements for NVD flight training (i.e. in flight operational aspect that is fleet specific) of both instructors and aircrew throughout the RCAF. This work is to be carried out in collaboration with CFSSAT (2 CAD) and Health Services aeromedical advisors and shall meet the requirements of NATO Standard AAMedP-1.21 where applicable. Requirements for all aircrew are to be incorporated in the FOM. [3.1.45, 3.1.47]

4.3.6 2 CAD Dir AF Trg to conduct a Training Needs Analysis of aeromedical training with a focus on SD recognition and recovery (with and without NVGs), as well as general NVG use and training requirements once the new Spatial Disorientation Trainer contract has been awarded. [3.1.43, 3.1.44, 3.1.48]

4.3.7 1 CAD SSO Met to formalize training for Met Tech on process used to obtain illumination levels (i.e. mlx value). [3.1.40]

4.3.8 2 CAD Dir AF Trg, via CFSSAT and with support from 1 CAD SSO Met, to formalize training for aircrew on process used to obtain illumination levels (i.e. mlx value). [3.1.40]

4.3.9 The 4 CDSB Garrison to modify the Garrison Fire Hall PA System to allow for simultaneous message broadcast in both the Garison Fire Hall and the Crash Fire Hall. [3.1.49]

4.3.10 The 4 CDSB Garrison to develop options to use Wegner Point as an emergency launch site for their watercraft. [3.1.51]

4.3.11 The 4 CDSB Garrison to adjust their first responders' plan and equipment to ensure their readiness to respond to worst-case scenarios (see para 2.13.4 for details). [3.1.52]

4.3.12 The 4 CDSB Garrison to review and update their ERP to correct errors and incorporate lessons learned from the accident of *Hammer 31*. The ERP should be harmonized with the 1 Wing ERP if the BFSO position is going to be assigned to the 1 Wing WFSO. In addition, the revised ERP to document how OSCER would be supported with a scalable support team and specify an alternative plan for cases where the OSCER vehicle is unavailable for use. [3.1.53, 3.1.54, 3.1.55, 3.1.56, 3.1.59]

4.3.13 Following the ERP update, the 4 CDSB Garrison to run a tabletop exercise, followed by an actual Crash Exercise within 12 months of the update to validate the new ERP. [3.1.58]

4.3.14 1 Wing A3 to develop an ERP to document key personnel roles and responsibilities. The ERP should be tailored to the reality that 1 Wing Squadrons are not collocated and are dispersed across the country. The ERP should determine how OSCER resources (or go-kit as its commonly referred to) would be deployed to support accidents that might occur off base (inaccessible by road). The ERP should be harmonized with the 4 CDSB ERP if the WFSO position is going to be assigned to the 4 CDSB BFSO. [3.1.56, 3.1.57]

4.3.15 Following the creation of the ERP, 1 Wing A3 to run a tabletop exercise, followed by an actual Crash Exercise within 12 months of publication to validate the new ERP. [3.1.57]

4.3.16 CH147F WSM (Weapon System Manager) to verify if the deficiencies highlighted during the QETE testing of the Emergency Exit Light system might have an impact on the fleet; in particular: (1) consider a limited sample inspection of inertial switch assemblies to confirm no internal corrosion of relay contacts exists; (2) consider replacement of emergency lights where housing cannot be hermetically sealed due to fastener system damage; and (3) consider implementing maintenance activities to verify and maintain optimal charge capacity of emergency lighting internal batteries, both service-run and drawn from supply stock. [3.1.62, 3.1.63, 3.1.65]

4.3.17 CH147F WSM to work with SSO Tac Avn and Director of Air Requirements to assign a higher priority to implement the existing OEM modification for HEELS on the CH147F fleet. [3.1.66, 3.1.67]

4.3.18 1 CAD Dir Fleet Rdns to amend RCAF FOM Aircrew Currency Requirements for fleets operating with CRR and mandate the use of CRR during annual egress training. [3.1.68, 3.1.69, 3.1.71]

4.4 AIRWORTHINESS INVESTIGATIVE AUTHORITY REMARKS

4.4.1 This is yet another poignant reminder of the risks associated with military aviation, and an example of a preventable fatal accident. A tragic scenario that took very little time to develop, and for aircrew to succumb to unrecognized loss of situation awareness. The low illumination coupled with the glassy water conditions made for challenging flying conditions during a busy night flight, where the high workload in a short flight created the conditions where neither pilot was effectively monitoring crucial flight instruments. The RADALT low altitude Bug setting is a tool that must be used to mitigate risk in such situations. This is a lesson that we are re-learning, and we need to better adapt our procedures to incorporate such tools. We all know this, but we must remain vigilant at all times, even more so when operating at tactical levels.

4.4.2 The Chinook (as most of our aircraft) is a complex machine. We must ensure that our newest aircrew are given the required priority to gain proficiency and to develop confidence. Training courses that consistently overrun the planned training time, may indicate that the current system is not producing aircrew with efficacy. Whatever the resource situation, our OTFs/OTUs need priority to allow for timely training. As the RCAF engages in the most aggressive platform integration since WWII, the demands of FG and FE need to be carefully balanced in order to allow our crews to properly train and gain proficiency.

4.4.3 Lastly, in the past 20 years, the RCAF has experienced four fatal Rotary-Wing accidents. Three of these involved unplanned ditching into the water: (1) 13 Jul 06, CH149 Cormorant inadvertent water entry, (2) 29 Apr 20, CH148 Cyclone crash at sea, and (3) 20 Jun 23, CH147F Chinook crash in the water. Although regulations allow for aircrew to fly without an LP/SV or EBS under certain conditions, the reality is that unplanned ditching does happen; all aircrew should be ready for such an event. It is just “kit” until you need it in an emergency situation. Everyone is responsible for their own ALSE; respect inspection cycles, and take the time to have it properly fitted, including following seasonal changes.

GAUVIN, JEAN-FRANCOIS 177
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J.-F. Gauvin
Colonel
Airworthiness Investigative Authority

ANNEX A - ABBREVIATIONS

AAMedP	Allied AeroMedical Publication
AC	Aircraft Captain
ACK	Acknowledge
AFIC	Air Force Interoperability Council
AGL	Above Ground Level
AHO	Above Highest Obstacle
AIA	Airworthiness Investigative Authority
AIF	Aircrew Information File
AIM	Airworthiness Investigation Manual
ALOS	Acceptable Level Of Safety
ALSE	Aviation Life Support Equipment
ALT	Altitude
AMSET	Aircraft Maintenance Standardization & Evaluation Team
AMT	Aeromedical Training
ANT	Advanced Night Test
ANVIS	Aircrew Night Vision Imaging System
AOI	Aircraft Operating Instructions
BFO	Basic First Officer
BFSO	Base Flight Safety Officer
CA	Canadian Army
CAD	Canadian Air Division
CAF	Canadian Armed Forces
CAP	Corrective Action Plan
CCDA	Cockpit Control Drive Actuator
CD REL	Centring Device Release
CDSB	Canadian Division Support Base
CESM	Cold Exposure Survival Model
CFB	Canadian Forces Base
CFIT	Controlled Flight Into Terrain
CFSSAT	Canadian Forces School of Survival and Aeromedical Training
CMBG	Canadian Mechanized Brigade Group
CO	Commanding Officer
CoC	Chain of Command
CRP	Crash Response Plan
CRR	Crewman Releasable Restraint
CRZ	Cruise
CVR	Cockpit Voice Recorder
CYWA	Petawawa Heliport
DAFCS	Digital Automatic Flight Control System
DFS	Directorate Flight Safety

DTAES...Directorate of Technical Airworthiness and Engineering Support
DTLP..Damage Tolerant Life Preserver
EAL..Energy Absorbing Liner
EBS..Emergency Breathing System
EDT..Eastern Daylight Time
ELT..Emergency Locator Transmitter
EMER-EXIT..Emergency Exit
ERP..Emergency Response Plan
FAR..Fatigue Assessment Report
FAST..Fatigue Avoidance Scheduling Tool
FATO..Final Approach and Take Off Area
FDR..Flight Data Recorder
FE..Flight Engineer
FG..Force Generation
fpm..feet per minutes
fps...feet per second
ft..foot (or feet)
FO..First Officer
FOM...Flight Operations Manual
FOV..Field of view
FS..Fuselage Station
FSIMS...Flight Safety Information Management System
FSO..Flight Safety Officer
G..measure of gravitational forces
GPS..Global Positioning System
HAZREP...Hazard Report
HEELS..Helicopter Emergency Egress Lighting System
HQ..Headquarter
HUD...Heads-Up Display
ILCA...Integrated Lower Control Actuator
in..inch
inHg..inch of mercury
INTR LTG...Interior Lighting
IP...Instructor Pilot
IR...infrared
IRU..Immediate Response Unit
JMC..Joint Met Centre
KIAS...Knots Indicated Airspeed
kg...kilogram
L...litre
LA...Launch Authority
LATEF...Land Aviation Test and Evaluation Flight

lbs	pounds
L/min	litre per minute
LP	Life Preserver
LP/SV	Life Preserver / Survival Vest
LRP	Long Range Patrol
m	meter
MA	Mission Acceptance
MAG BRAKE	Magnetic Brake
MALA	Mission Acceptance / Launch Authority
METAR	Meteorological Terminal Air Report
MFAU	Military Flight Advisory Unit
mlx	millilux
MFD	Multi-Function Display
NATO	North Atlantic Treaty Organization
NRC	National Research Council
NVG	Night Vision Goggles
OA	Operational Airworthiness
OEM	Original Equipment Manufacturer
OSCER	On-Scene Controller of Emergency Response
OSP	Occupant Safety Policy
OT&E	Operational Test and Evaluation
OTF	Operational Training Flight
OTU	Operational Training Unit
PA	Public Announcement
PF	Pilot Flying
PFD	Primary Flight Display
PM	Pilot Monitoring
POL	Petroleum, Oils, and Lubricants
Prog Book	Progress Book
Prog Card	Progress Card
QS	Qualification Standard
RADALT	Radar altimeter
RADALT bug	RADALT low altitude warning index
RAF	United Kingdom Royal Air Force
RARM	Record of Airworthiness Risk Management
RCAF	Royal Canadian Air Force
RCN	Royal Canadian Navy
RT	Recertification Training
RUET	Rotary-Wing Underwater Escape Training
SAR	Search and Rescue
sm	statute mile
SMD	Simulator Model Dataset
SMM	Standard Manœuvre Manual
SOAS	Special Operations Aviation Squadron

SOCD .... Statement of Capability Deficiency
SOP .... Standard Operating Procedure
SP .... Student Pilot
SSO OA .... Senior Staff Officer Operational Airworthiness
SSO Tac Avn .... Senior Staff Officer Tactical Aviation
Tac ASVS .... Tactical Aircrew Survival Vest System
Tac Avn .... Tactical Aviation
TAF .... Terminal Area Forecast
TAFO .... Tactical Advanced First Officer
TCAS RA .... Traffic Collision Avoidance System Resolution Advisory
TE .... Training Establishments
TEP .... Training Education Plan
THS .... Tactical Helicopter Squadron
TSV .... Training Standardization Visit
UCR .... Unsatisfactory Condition Report
UK .... United Kingdom
US .... United States
UTC .... Coordinated Universal Time
VCDS .... Vice Chief of the Defence Staff
VFR .... Visual Flight Rules
VMC .... Visual Meteorological Conditions
VSI .... Vertical Speed Indicator
WFSO .... Wing Flight Safety Officer
WSM .... Weapon System Manager

ANNEX B - LIST OF TABLES, FIGURES AND PHOTOS

List of Tables

List of Figures

List of Photos

ANNEX C - REFERENCES

1. The following is a list of references that were consulted or used in the formulation of this investigation report.

A. B-GA-002-147/FP-001, CH147F Chinook Standard Manœuvre Manual (Change 4), 01 Jan 18.

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DD. CH148 Cyclone Co-Pilot Training Education Plan, Version 4.3, 14 May 24.

EE. CH149 Cormorant Search and Rescue (SAR) First Officer Training Plan, Version 0, 24 Oct 08.

FF. RCAF Training Education Plan – CH147F First Officer Course, Version 4.0, 15 Dec 19.

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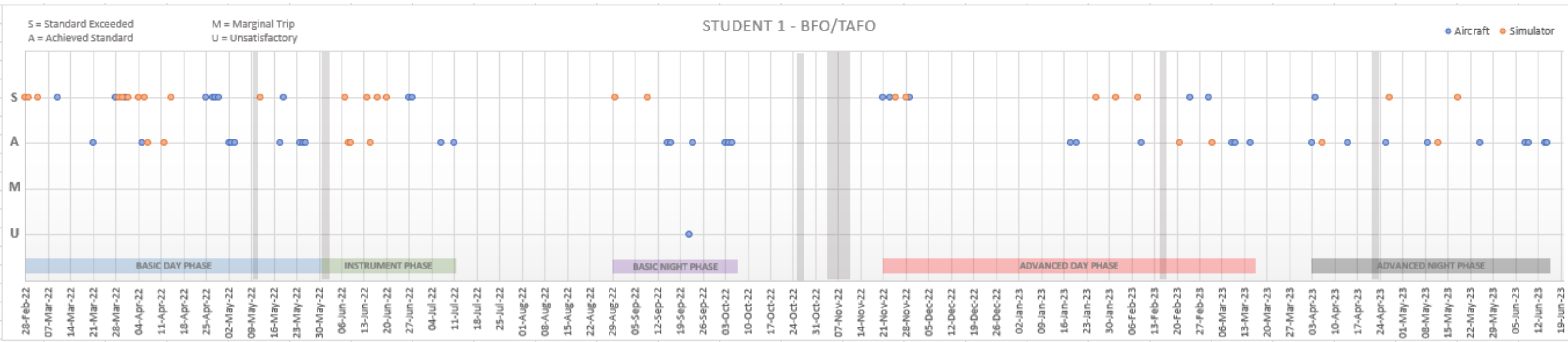
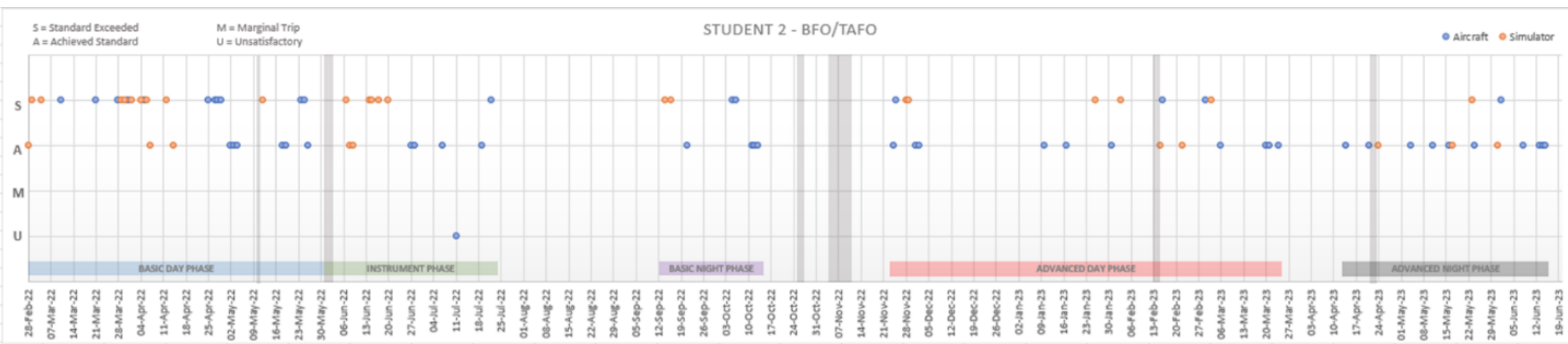
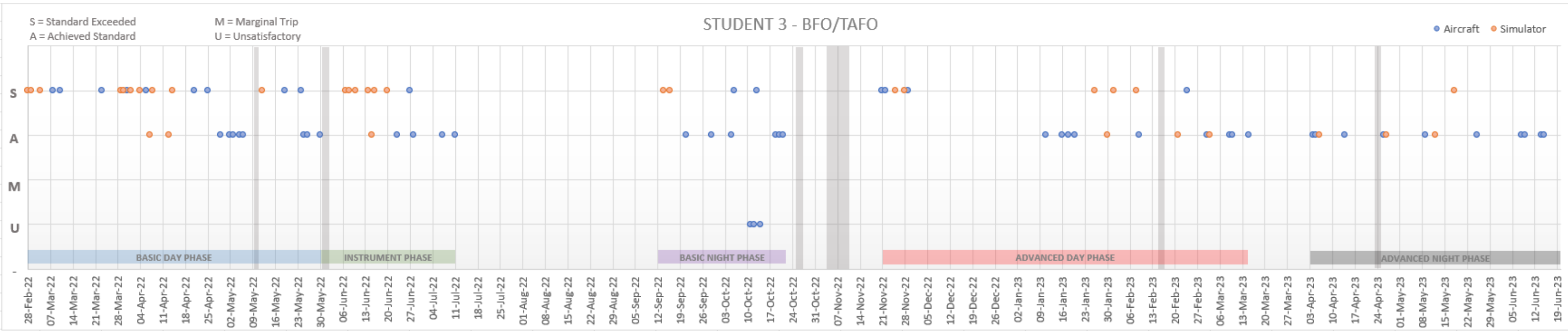
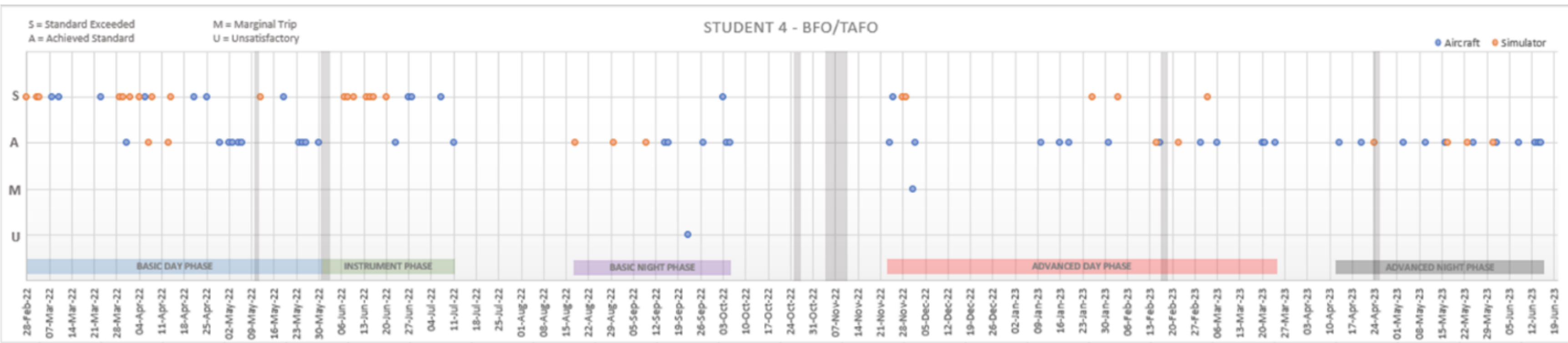
ANNEX D - BFO 2102 & TAFO 2202 COURSE PROGRESSION AND CONTINUITY

1. The following four graphs are depictions of the course progression for the four SPs who were on courses BFO 2102 and TAFO 2202. The information was derived from each of the four SP's Prog Books.







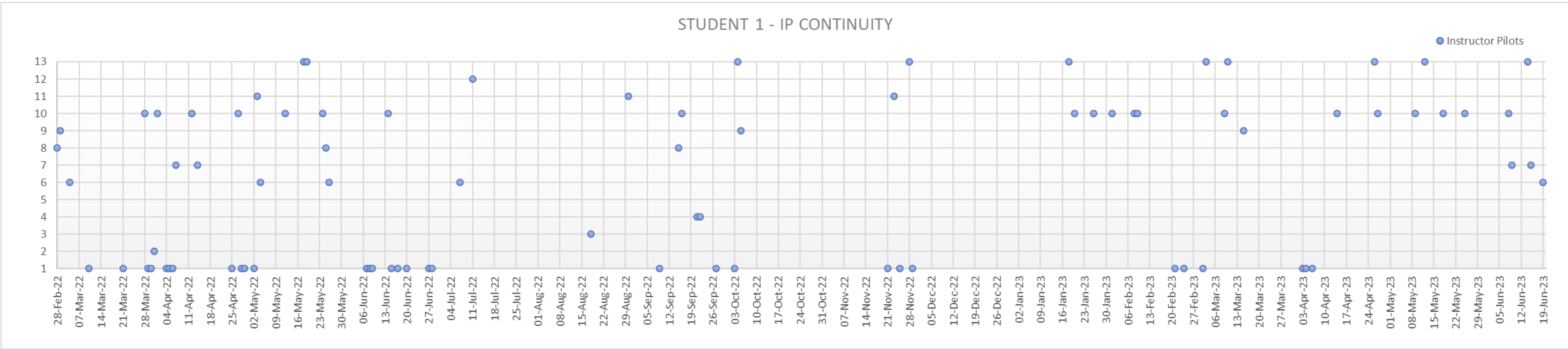


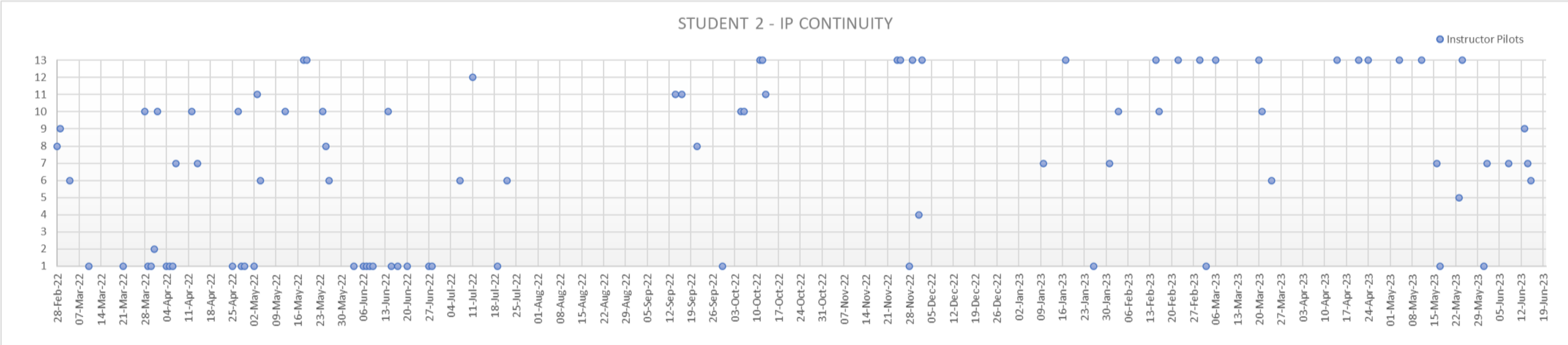
NOTES:
1. Blue dots are the air lesson plans carried out in the actual aircraft.
2. Orange dots are the lesson plans carried out in the flight simulator.
3. The coloured banners at the bottom of the graph represent each course phase.
4. Shaded areas represent ground training periods.
5. The vertical scale (left) represents each individual lesson plan performance evaluation as described on the top-left of each graph.

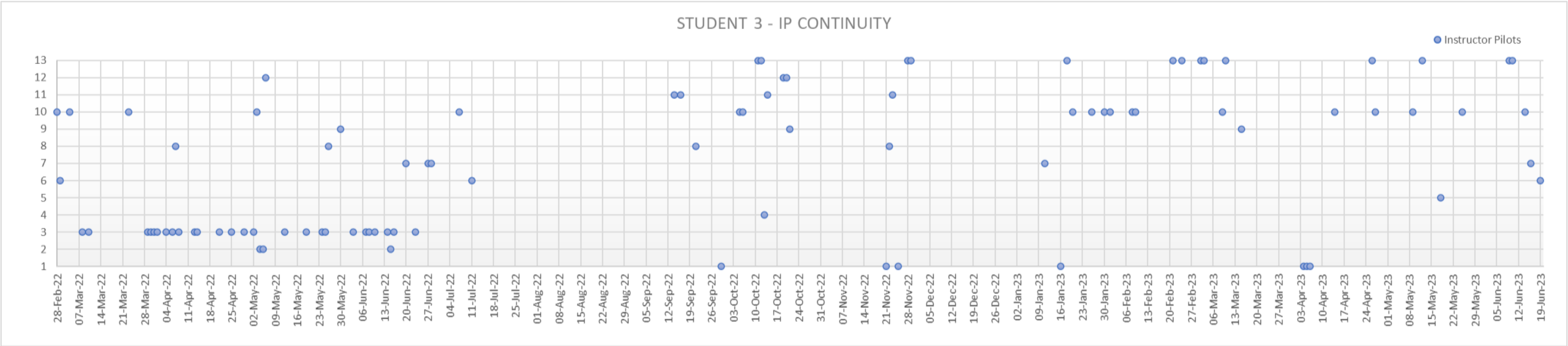
Annex E to
1010-CH147F-197571 (DFS 2-5-3)
7 October 2024

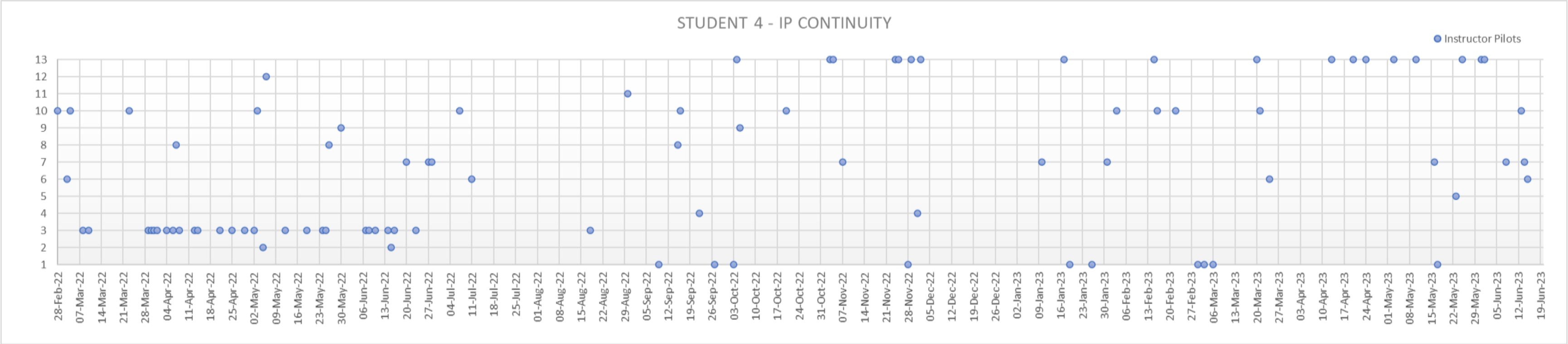
ANNEX E - STUDENT PILOTS INSTRUCTOR CONTINUITY

1. The following four graphs are depictions of the IP continuity for the four SPs who were on courses BFO 2102 and TAFO 2202. The information was derived from each of the four SP's Prog Books.





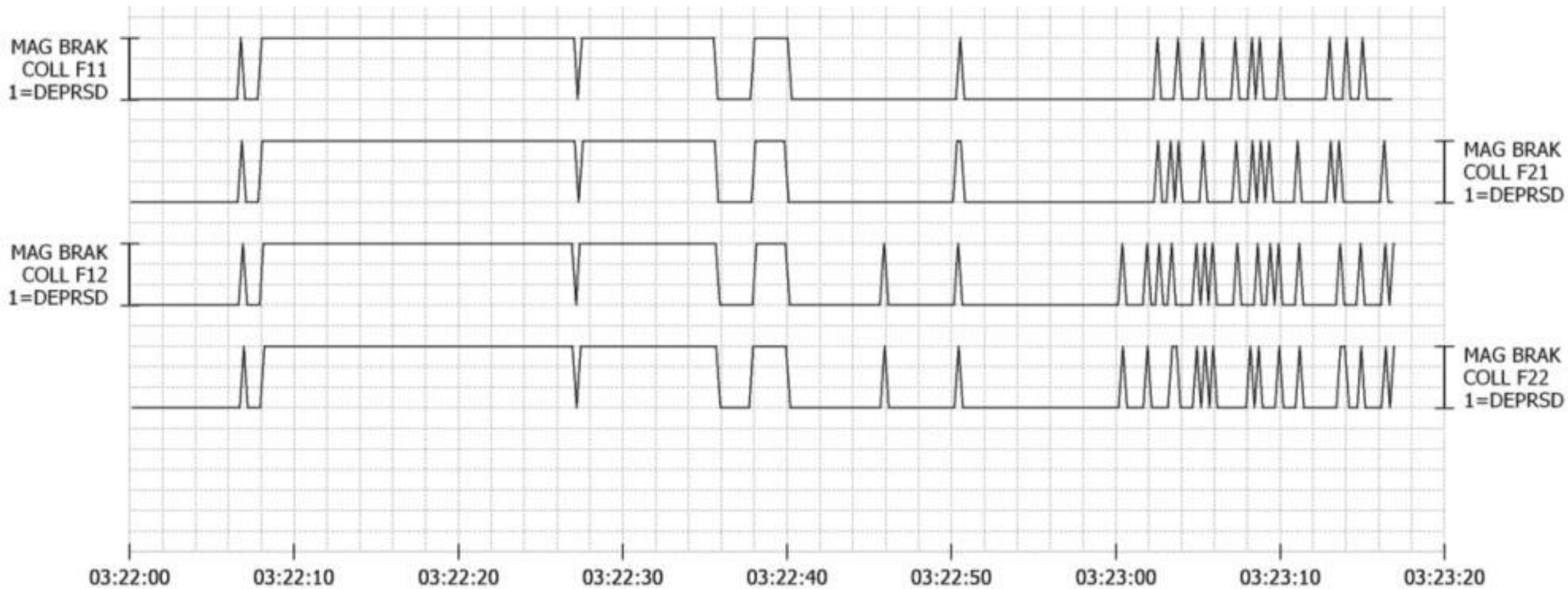




NOTES:
1. Blue dots are all the air lesson plans carried out, either in the actual aircraft or in the flight simulator.
2. The vertical scale (left) represents each IP that taught on BFO 2102 & TAFO 2202.

ANNEX F - FLIGHT DATA (MAG BRAKE) – CH147310

1. The following trace is an extract from the CH147310 FDR for the accident flight. It depicts the four channels that record thrust control lever MAG BRAKE activations.



ANNEX G - *HAMMER 31* FLIGHT PATH AND CERTAIN FDR PARAMETERS

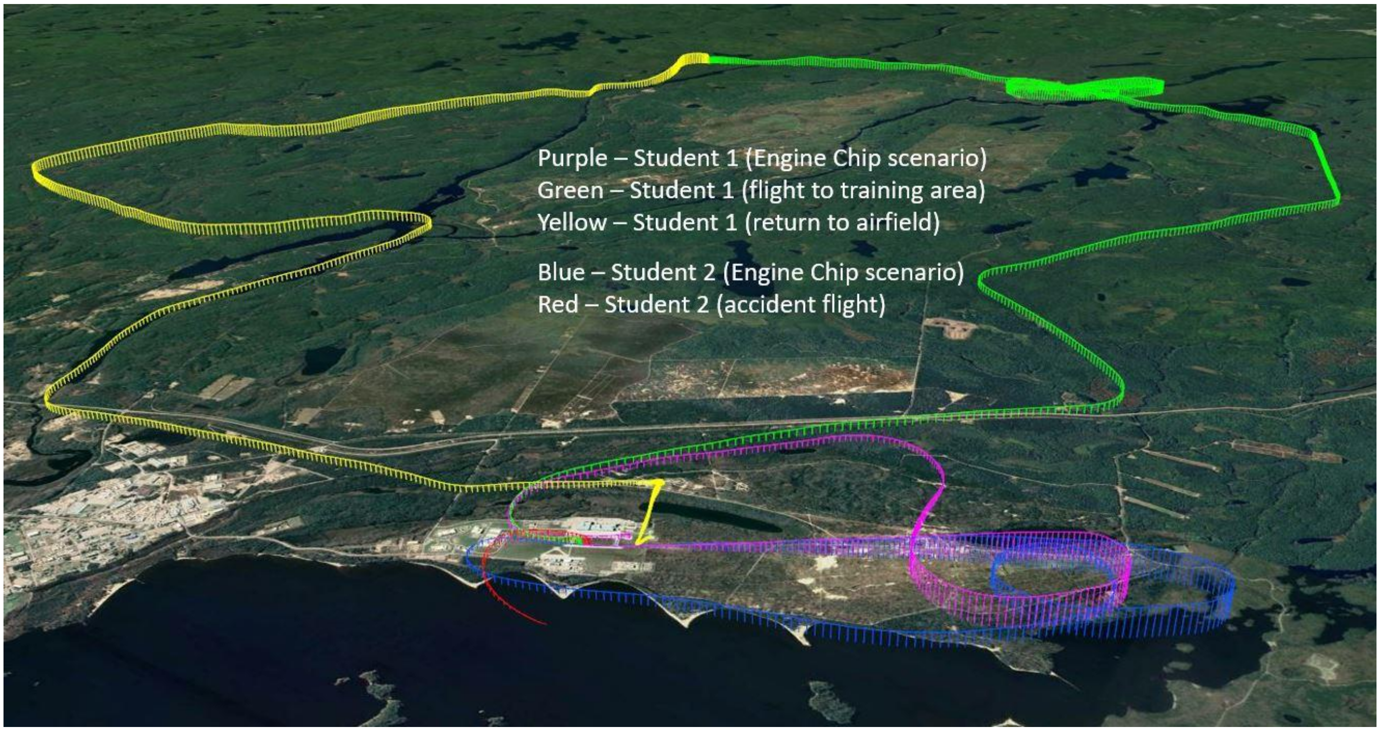


Figure G-1: Hammer 31 Flight Path for entire mission (SP 1 and SP 2)

Figure G-2: Flight Path for the occurrence leg, indicating the accident location

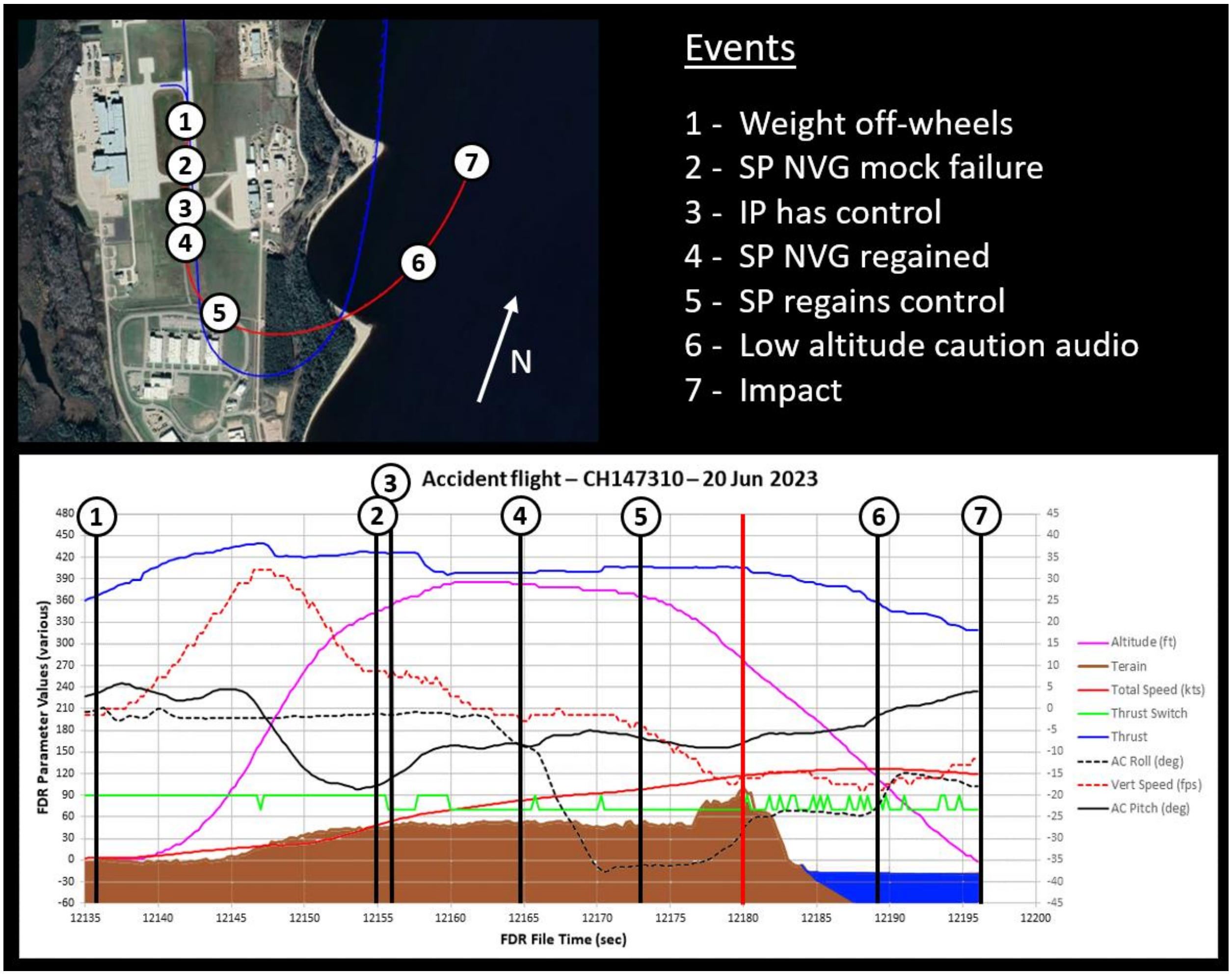


Figure G-3: Flight Path and graph of selected FDR parameters, highlighting specific events.

<u>NOTE 1:</u> Tan area represents the approximate ground profile below the flight path, based on RADALT information from FDR; area in blue represents the river.

<u>NOTE 2:</u> The red vertical line indicates the location of the treeline (highest obstacle).

ANNEX H - EXTRACTS FROM THE FLIGHT OPERATIONS MANUAL (FOM)

2.4.9.2 CH147F Extended Overwater Operations

1. For the CH147F, extended overwater operations is considered as flight 10 minutes or more from shore. The following restrictions apply to extended overwater flight for the CH147F:

   a. Only minimum essential personnel shall be carried aboard any flight as tasked by the flight authorization officer. In any case, not more than 36 personnel including crew shall be carried on board;

   b. All personnel shall wear a life preserver or LP/SV, and all qualified personnel shall wear an EBS;

   c. All passengers shall receive a safety brief which includes approved seating locations and egress procedures. Safety brief shall be modified to include the following:

      (1) Forward cabin exits are primary ditching exits for all cabin occupants; and

      (2) Passengers seated in proximity to the 19 inch emergency circular window exits shall be diligently briefed on the use and operation of these tertiary exit windows.

   d. Sea State 4 is the maximum sea state authorized for extended overwater flight. This restriction can be waived as required for the conduct of real-world operations on the authority of the Comd RCAF;

   e. Armoured plates are not to be worn by any crew or passengers. This restriction can be waived as required for the conduct of real-world operations by Comd 1 CAD;

   f. Extended overwater operations with civilians who are not qualified RUET requires approval by Comd RCAF;

   g. Gun mounts shall be stowed internally unless an operational requirement exists; and

   h. The use of the Mobility Box as passenger seating is prohibited.

3.6.2.24 RUET/EBS Training

1. All aircrew shall successfully complete RUET/EBS training in accordance with reference N.

2. Aircrew who do not successfully complete RUET/EBS training within one year of completing the OTU (or Refresher Trg) are not authorized to conduct overwater flight.

3. Aircrew who do not successfully complete RUET/EBS within the validity period or who do not complete the annual ALSE refresher briefings are not authorized to conduct overwater flight.

4. Pilots new to 1 Wing shall complete RUET within one year of being awarded their flying category. Those who are not RUET qualified within this one year period are not authorized to conduct overwater flight.

5. For the purpose of this order, Overwater Flight is defined as flight over water below safe single engine speed.

4.2.2.9 Life-Jackets/Emergency Breathing Equipment/Survival Vests

1. Personal Survival Vests or crewmember Life Preserver/Survival Vests (LP/SV) shall be worn as dictated by mission requirements.

a. Air Mobility. Life jackets easily accessible to all crew shall be carried on all Air Mobility aircraft. Life jackets are to be carried for all passengers and passengers are to be briefed on the location and operation of the life jackets when:

(1) that portion of the aircraft's flight will be more than 50 nautical miles (nm) from land;

(2) the arrival or departure path will be immediately overwater; and

(3) all occupants of Air Mobility aircraft shall wear approved personal floatation devices/LP/SV with Emergency Breathing System (EBS) when flying below 500 ft during overwater Search and Rescue (SAR) missions and/or training.

b. Long Range Patrol (LRP). Sufficient life jackets shall be available for each LRP aircraft occupant during overwater flights and worn when directed by the AC.

c. Rotary-wing Aircraft. Crewmember LP/SV should be equipped with Emergency Breathing System (EBS) as dictated by mission requirements.

ANNEX I - AIRCREW INFORMATION FILE (AIF)

1. This annex contains the three AIF that were published in the days following the accident of CH147310.

3000-1 (U TAC STDS O)

Date in electronic signature

450 THS AIF 23-18

EMERGENCY BREATHING SYSTEM (EBS) AND LIFE PRESERVER (LP)

Ref: A. rcaf-flight-operations-manual-21-june-2023.pdf (mil.ca) 2.4.9.2 CH147F Extended Overwater Operations

1. Here is a new unit directive supplementing Ref A:

   a. All aircrew shall wear the following ALSE on all flights overflying any type of water bodies:

      (1) Emergency Breathing System (EBS); and

      (2) Life Preserver (LP).

2. Aircrew who has not yet completed the RUET/EBS training, shall complete a unit EBS familiarization training prior to commencing flying training in the aircraft.

3. The LPSV or the Eagle vest with TDLP and leg straps meet the LP requirement. To reduce the ALSE inspection workload requirement, aircrew have the following options:

   a. Option 1: the following local ALSE SOP are being implemented:

      (1) LPSV (for flight overwater, most local flight)
      (2) Eagle vest without TDLP (for tactical training flight over land only.)

   b. Option 2:

      (1) Eagle vest with TDLP and leg straps.

4. Flights with any crew member not wearing an EBS or LP are restricted from flying over any type of water bodies.

5. The effect and impact of this new directive will be evaluated in a near future to decide if it needs to be permanently implemented in flying orders.

6. Questions may be directed to the U Tac Stds O.

By Air to Battle!

DONNELLY, JAMES 469
Digitally signed by DONNELLY, JAMES 469
Date: 2023.06.26 14:24:03 -04'00'

Maj Donnelly
Ops O
450 THS
8453

3000-1 (U TAC STDS O)

Date in electronic signature

450 THS AIF 23-19

FLIGHT IN LOW ILLUMINATION CONDITION

Ref: A. rcaf-flight-operations-manual-21-june-2023.pdf (mil.ca) 2.2.6.3 Minimum Altitudes

1. The following are temporary unit restrictions supplementing Ref A:

    a. The minimum height authorized for low flying training at night in low illumination condition **≤ 1.5mlx is 100' AHO**.

    b. The minimum height authorized for low flying training **at night overwater is 100' AHO**.

2. The intent of this revised restriction is to standardize the additional safety margin required in low light condition from ref A:

    a. Environmental conditions (recirculating phenomena, light conditions, etc…) and/or operational conditions (mission complexity, aircraft manoeuvres, speed of approach, etc) may necessitate **adding an additional safety margin** to these limits.

3. The effect and impact of this new restriction will be evaluated in a near future to decide if it needs to be permanently implemented in flying orders.

4. Questions may be directed to the U Tac Stds O.

By Air to Battle!

DONNELLY, JAMES 469 — Digitally signed by DONNELLY, JAMES 469 Date: 2023.06.26 14:33:27 -04'00'

Maj Donnelly
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450 THS
8453

3000-1 (U TAC STDS O)

Date in electronic signature

450 THS AIF 23-20

OVERWATER FLIGHT AT NIGHT

Ref A. CH147 SMM (mil.ca) Task 200 Perform Terrain flight para 44.

1. The following is a new temporary unit Standard Operating Procedure (SOP) supplementing Ref A:

   a. In order to minimize spatial disorientation and avoid an unintentional descent to the water, the NATIVE modes **ALT (or ALT+R) SHALL** be **"ACTIVE"** when flying under the following combined condition:

      (1) at night;

      (2) at or below 200' AHO; and

      (3) over any bodies of water (except small bodies of water taking only few second to cross).

   b. When NATIVE modes are utilized IAW para 1a above, descents **SHALL** maximize the use of automation by using the **UP/DOWN** switch. The descent shall be:

      (1) announced by the PF,

      (2) acknowledged by the PM,

      (3) monitored by the entire crew and

      (4) on reaching target height the PM shall confirm Native Mode ALT (or ALT+R) "ACTIVE".

   c. Climbs may use the thrust break as required.

   d. Be alert to any unannounced changes in the flight profile and be prepared to take immediate corrective actions. (e.g: take control, call "Up Up Up")

2. The effect and impact of this revised SOP will be evaluated in a near future to decide if it needs to be permanently implemented in CH147F Chinook Standard Manoeuvre Manual.

3. Questions may be directed to the U Tac Stds O.

By Air to Battle!

DONNELLY, JAMES 469 Digitally signed by DONNELLY, JAMES 469 Date: 2023.06.26 14:30:48 -04'00'

Maj Donnelly
Ops O
450 THS
8453

ANNEX J - 450 THS UNIT PRIORITIES

450THS UNIT PRIORITIES

Draft v0.1 (26 Oct 2022)

Pri Level	Tasks	Description
Pri 1	URGENT	High Urgency & High Impact
Pri 1A	Urgent MTF / GR / MRP	MTF impacting unit response capability
Pri 1B	Urgent Force Employment (FE) Task	Op LENTUS / National Tasks / HR Response
Pri 2	HIGH/CRITICAL	either High Urgency or High Impact
Pri 2A	Critical RFE / Major Exercises	RFE impacting our RTHR / NTL / HR posture
Pri 2B	Critical T&E	T&E ISO critical capability
Pri 2C	Critical APC/IRT	Impacting member category & member is required to support Flypro
Pri 2D	Critical Force Generation (FG)	Training flight addressing a critical unit deficiency
Pri 3	CORE/ESSENTIAL	Mid Urgency & Mid Impact
Pri 3A	Essential MTF / GR	routine MTF IOT achieve YFR target / Fleet stagger / support flypro + 1 B/U
Pri 3B	Currency Flight / FSim	E.g: Check Flights (APC / IRT / Spec (FIC)) RLP Recurrency Flight
Pri 3C	Core FG (Continuation trg)	Impact our midterm capacity to MTF / FG / FE E.g.: o MTP Course (Impacting MTF support) o FIC / ICP (Impacting FG support) o TACC / BTAC / ATAC / TEWIC/Category o Upgrade (Impacting AC support) o Aerial Gunnery / MFC (HR posture)
Pri 3D	Core FG (Initial Training)	FG ahead of planned attrition or mandated growth E.g.: o CT / RT (prioritize for a greater return on investment) o FE/LM course o BFO/TAFO o DG Trg
Pri 3E	Essential T&E	
Pri 3F	Essential RFE / Exercises	Supporting other unit essential FG: CMERT, HUSO...
Pri 3G	Essential Proficiency Flight	Supporting Plt/FE/LM/DG progression / upgrade...
Pri 4	Medium/Non-Urgent/Routine	either Low Urgency or Low Impact
Pri 4A	Non-urgent MTF / GR	Beyond YFR target / +2 B/U
Pri 4B	RFE	SOF Integration
Pri 4C	RFE	VIP Transport
Pri 4D	RFE	Non-compulsory tasks - Para / Helocast / Mountain Flying
Pri 4E	Non-urgent Currency	Check Flight / RLP with rolex flexibility
Pri 4F	Non-urgent FG – Continuation Trg	no short term requirement, on an opportunity basis
Pri 4G	Non-urgent FG – Aircrew Initial Trg	Extra candidate, on an opportunity basis
Pri 5	Low/Extra	Low urgency & Low Impact
Pri 5A	Extra RFE	Special Event: Airshow, Visit, Family Day...
Pri 5B	Extra RON / Proficiency Flight	

ANNEX K - MISSION ACCEPTANCE / LAUNCH AUTHORITY (MALA)

1. Using available information, the investigation generated the LA worksheet that would have been generated/submitted by the crew of *Hammer 31*. It may not be an exact representation of the worksheet the crew would have generated.

Line	Item		Low (0 Points)	Medium (1 Points)	High (3 Points)	Severe (CO / ATF Comd)	Total
	CREW						
1	Fatigue Assessment (per crewmember)	Hours flown in last 30 days	< 60 hrs	60-75 hrs	75-85	85-100	
2		Op Tempo	< 5 consecutive days of 12 hours or more	≥ 5 consecutive days of 12 hours or more	≥ 7 consecutive days of 12 hrs or more	3 consecutive duty days of 13 hrs (NVG) / 16 hrs (day)	
3		Day/Night Ops Transition	Switch occurred 24-36 hrs ago	Switch occurred 12-24 hrs ago	Switch occurred < 12 hrs ago		
4		Crew Rest	≥ 12			< 12 hrs	
5		FAR Score[1]	0-5		6-11	≥ 12	
6	EXPERIENCE – AC	<1000 hrs RW	≥ 600 hrs on type	300 - 600 hrs on type	< 300 hrs on type		
7	EXPERIENCE – AC	>1000 hrs RW	≥ 300 hrs on type	100 - 300 hrs on type	< 100 hrs on type		
8	EXPERIENCE – FO		≥ 200 hrs on type	<200 hrs on type		No FO / Not qualified / famil flight[3]	
9	EXPERIENCE – FE		≥ 200 hrs on type	< 200 hrs on type	No FE / LM		
10	Proficiency[2] (per crewmember)			Day BH&E > 90 days IF app / IIMC > 90 days Night BH&E > 60 days	Night BH&E > 90 days		
11	Currency (per crewmember)		All crew members current		Other crew not current or w/in 7 days of qualification expiry[3]	AC not current on non-compulsory qualification planned	
	ENVIRONMENT						
12	Weather[4]	VFR (Day)	ceiling ≥ 1000'; or visibility ≥ 3 SM	ceiling < 1000'; or visibility < 3 SM	ceiling ≤ 500'; or visibility ≤ 2 SM	ceiling ≤ 300'; or visibility ≤ 1.5 SM	
13		VFR (Night)	ceiling ≥ 1000' visibility ≥ 6 SM	ceiling < 1000' visibility < 6 SM	ceiling < 700' visibility ≤ 4SM	ceiling = 500' visibility = 3 SM	
14		IFR	IMC - no alt req / VMC	IMC - alt req	IMC - field departure		
15	Setting	Temperature / DA		Landing DA > 6000'	Landing DA > 8000'	WBGT ≥ 38C, Open Door ops ≤ -18C, or Windchill ≤ -36C	
		Illumination (MLLX)		Illum (0.85>mlx<3)[5]	Illum (< 0.85mlx)[5]		
		Winds		Winds > 30kts	Winds > 35kts		
16		Other	Day DVE Ops	Night DVE Ops	Known Icing Over water Ops	Airshow flying demo Sea State ≥ 4	
	MISSION SPECIFIC						
17	Changes (post MA)	Profile	No			Yes - Consult MA to assess RH change	
18		Crew	No	Yes - New crew member(s)	Yes - New AC	Yes - New AMC (within last 24h)	
19		Notice[6]	≥ 12 hrs	< 12 hrs	< 6 hrs	< 3 hrs	
	AIRCRAFT SPECIFIC						
20	Pwr Margin		≥ SMM limit	SMM limit, No HOGE		< SMM limit[7]	
21	Defects			Deferred, no impact to mission	Deferred, with impact to mission		
	OVERALL EVALUATION						
	TOTAL SCORE		0	3	0		3
	Approved By:		Signature:			DTG:	
	Launch Authority	Outside the CO/ATF Comd's authority				A/R (Notes)	A/R (Notes)
		Within the CO / ATF / TAD Comd's authority			> 3 'High'	Any Severe	>10
		CO/ATF Comd's delegated authority to flt supervisor[8]			≤ 3 'High'		> 3 points
		Aircraft Commander's authority to approve					≤ 3 points

NOTES (A/R):
1 Fatigue Risk Assessment Report completed / submitted to FDO
2 Night considerations do not apply if flight is conducted day only
3 Not applicable to UT flight with instructor
4 Flying Orders dictate op limits - METAR / TAF (most restrictive)
5 Refer to "weather corrected" mllx
6 Time prior to launch when msn / SoM change nec re-plan.
7 Requires 1 CAD / Dir Flt Rdns endorsement. Refer to Appendix C - Request through A3.
8 Cannot be further delegated or re-delegated