CANADIAN FORCES
FLIGHT SAFETY INVESTIGATION REPORT (FSIR)

FINAL REPORT

FILE NUMBER:	1010-CH146434 (DFS 2-4)
FSOMS:	139123
DATE OF REPORT:	29 October 2012
AIRCRAFT TYPE:	CH146 Griffon Helicopter
DATE/TIME:	06 0908Z July 2009
LOCATION:	Forward Operating Base, Afghanistan
CATEGORY:	"A" Category Accident

SYNOPSIS

Aircraft CH146434 was the formation lead of a two-helicopter formation tasked with transferring passengers to and from a Forward Operating Base (FOB) in Afghanistan. The passengers were delivered to the FOB in the morning without incident. At 0841Z (1311 local) the formation departed to retrieve the passengers. Due to wind direction and obstacles, the pilots elected to land in the northern corner of the FOB instead of the designated landing site to optimize takeoff distance available for the subsequent departure. The number two (#2) aircraft landed first to collect its passengers, completed the takeoff and cleared the HESCO Bastion Concertainer ®, a seven to eight foot-high wire mesh wall filled with earth and stone referred to as the barrier in this report, by an estimated 10 feet. The accident aircraft landed next and collected its passengers. As power was increased for takeoff, a very large dustball developed. Immediately after takeoff, the aircraft began to drift forward and right, and shortly thereafter struck the barrier, rotated 90 degrees left, rolled onto its right side and immediately caught fire. Two pilots and one passenger exited the wreckage. One pilot was unharmed, one sustained minor injuries and the passenger suffered serious injuries. The remaining three personnel did not escape the aircraft and perished in the crash. The aircraft was destroyed.

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ANNEXES

1 FACTUAL INFORMATION

1.1 History of the Flight

1.1.1 The aircrew were tasked with the mission of inserting four passengers into a Forward Operating Base (FOB) in Afghanistan and to extract them a few hours (hrs) later. The accident aircraft, CH146434 was the formation lead of a two helicopter formation assigned to this mission. The number two (#2) aircraft was CH146414. Throughout the report, the two aircraft will be referred to as the accident aircraft and the #2 aircraft. With four passengers in total, the plan was for each aircraft to carry two passengers. The accident aircraft had a total of six people on board: the aircraft captain (AC), the first officer (FO), a Flight Engineer (FE), a Door Gunner (DG), one Canadian soldier and one Coalition soldier. The passengers were picked up in the morning by their respective aircraft and were flown to the FOB. The landing was carried out in sequence, with one aircraft landing while the other circled overhead. The insertion was conducted at the designated landing zone and was uneventful.

1.1.2 After the insertion both aircraft returned to Kandahar Airfield (KAF) to wait for the afternoon extraction mission. Once the passengers were ready for pick-up the aircraft departed KAF for the FOB. On arrival, as directed by the accident AC, the #2 aircraft was the first to land. Due to a wind shift from the morning insertion the approach was conducted in the opposite direction from that used previously, on a heading of approximately 210 degrees (º) magnetic (M). The #2 aircraft landed past the midway point within the FOB, picked up its two passengers and departed, only clearing the top of the barrier by approximately 10 feet (ft). The crew of the #2 aircraft informed the crew of the accident aircraft via radio that there was a large dustball[1] and that the takeoff required "a lot of power." In order to provide maximum room for obstacle clearance on departure, the accident aircraft then landed in the first third of the length of the FOB. After landing the accident crew retarded both throttles to flight idle in order to reduce the dustball enough to enable them to see the passengers approaching the aircraft.

1.1.3 Once the two passengers were on board, the crew of the accident aircraft developed their takeoff plan taking into consideration the #2 aircraft's departure, information provided by the #2 aircraft and the configuration of the FOB. The first officer (FO) intended to conduct an Instrument Takeoff (ITO) but in order to maximize vertical obstacle clearance the aircraft captain (AC) suggested to the FO to use more power than normal. The pilots decided to initiate a Maximum Performance Takeoff (MPTO) and then transition to an ITO

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[1] A dustball is the common term used to describe the dust cloud produced by the helicopter main rotor downwash on takeoff or landing. Brownout is the common term used to describe the degraded visual environment / conditions / phenomena caused by a dustball. The NATO description of Brownout, Whiteout, Dustball and a Degraded Visual Environment (DVE) is provided in Annex B.

once visual ground references were lost. A departure heading of 210ºM was briefed to maintain lateral separation from obstacles on either side.

1.1.4 The first officer, who was seated in the right seat and was the flying pilot (FP), rolled the throttles up to 100 percent (%) rotor revolutions per minute (RRPM) and a severe dustball started to develop. The FP increased power and initiated the MPTO sequence while maintaining control of the aircraft using visual ground references. As is standard procedure, the non-flying pilot (NFP) called mast torque (Qm) from 80% to 95% in increments of 5%. When the NFP called 95% Qm the FP quickly cross-checked the inter-turbine temperature (ITT) gauge and noticed that it was reading approximately 840^{o} - 850^{o} Celsius (C). At that moment, the NFP in the left seat, also using visual ground references noticed right drift and advised the crew they were drifting right, as per standard procedures. At the exact same time the FE, who was located on the right side rear cabin, stated that he was losing visual ground references. The FP acknowledged the drift call by the NFP and looked outside but he no longer had visual ground references due to the intensity of the dustball. The FP immediately referred back to the cockpit instruments for the transition to an ITO, as previously briefed. He did not inform the crew that he had lost visual ground references nor did he inform them that he was flying solely referencing cockpit flight instruments. Once the FP transitioned to instruments he noticed the aircraft heading was now 220ºM and immediately introduced a correction to bring the heading back to the pre-briefed 210ºM. The NFP could still see right drift so a second “drifting right” call was made. Within two seconds after the word “right” the aircraft impacted the barrier next to the FOB entrance. The FP saw the barrier just prior to impact but did not have sufficient time to manoeuvre the aircraft to avoid it. The aircraft collided with the barrier at the helicopter’s one to two o’clock position, between the aircraft nose and forward of the right pilot door hinge. Upon impact the aircraft rotated approximately 90º counter-clockwise, rolled on its right side and immediately caught fire.

1.1.5 One pilot was unharmed and one sustained minor injuries during the crash sequence. The FP noticed that the fire handles were lit and pulled both. However, the fire extinguishing activation switches that discharge the fire suppression bottles were not activated. Both pilots noticed the fire starting, unstrapped, and exited the aircraft through the broken windshield. Outside the aircraft, the pilots ran around the wreckage to assist possible survivors. As the fire quickly developed, they noticed movement in the cabin and saw one passenger attempting to exit the aircraft through the pilot’s windscreen. The pilots assisted the passenger in exiting the aircraft and all three moved to the HESCO barrier located in the middle of the FOB where the passenger advised the pilots that he had fractured his upper arm and required first aid. As the fire grew in intensity, the onboard ammunition began to cook-off[2] preventing any

[2] Cook-off: The premature ignition of an energetic material due to external heat (Defence Terminology Bank). In this case, cook-off refers to the explosion of the onboard ammunition.

further rescue attempts. The FE, the DG and the Coalition soldier were unable to exit the aircraft and perished.

1.2 Injury to Personnel

Injuries	Crew	Passengers	Others	Total
Fatal	2	1	0	3
Serious	0	1	0	1
Minor	1	0	0	1
No injury	1	0	0	1
Total	**4**	**2**	**0**	**6**

Table 1: Injuries to Personnel

1.3 Damage to Aircraft

1.3.1 The aircraft sustained A category damage and was destroyed by the collision with the barrier, the impact with the ground and the resultant post-crash fire. The aircraft sustained catastrophic fire damage from the nose of the aircraft to approximately station line 129 of the tail section. The fire intensity was such that very few recognizable aircraft parts remained (Annex A: Photo 1). The tail section suffered less fire damage but was significantly damaged as a result of the impact with the ground.

1.3.2 The transmission, main rotor head, main rotor blades and engines also sustained considerable fire damage. To facilitate the fire fighting process, these components were dragged out of the accident site by FOB personnel using a ground vehicle.

1.4 Collateral Damage

1.4.1 Collateral damage was limited to the barrier surrounding the accident site. There is a gap in the barrier that serves as an entrance to the FOB. This gap is protected by another barrier outboard of the FOB to protect the FOB entrance. This protective wall also sustained damage.

1.4.2 The aircraft fuselage struck and damaged the barrier's metal wire mesh structure (Annex A: Photo 2). All other damage to the barrier's retaining membrane (inner fabric) was caused by either fire or contact with flying aircraft debris. There were two main rotor blade strike marks at approximately a 45º angle on the right side of the impact point on the barrier (Annex A: Photo 3).

"Non-Controlled Goods / Marchandises Non-Contrôlées"

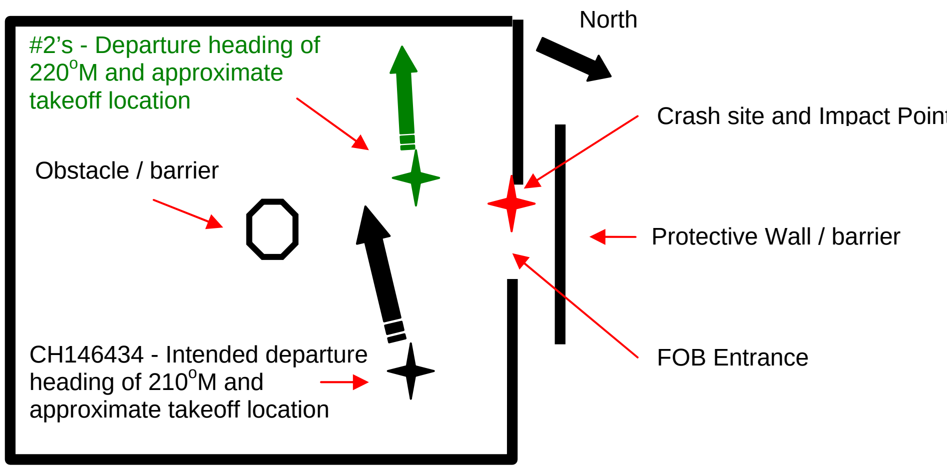

Figure 1: FOB Diagram – Not to Scale

1.5 Personnel Information

1.5.1 The crew was qualified, current and was properly authorized to fly the mission. They did not report any issues with fatigue, nutrition or hydration. The currency and duty information are summarized in Table 2 and Table 3.

	AC	FO	FE	DG
Proficiency Check	9 Mar 09	27 Oct 08	13 Feb 09	
Medical	VALID	VALID	VALID	VALID
Total Flying Time	998.3	904.5	1081.2	127.6
Hrs on Type	769.5	663.3	1081.2	127.6
Hrs Last 30 Days	48.7	68.9	30.2	14.9
Hrs Last 48 Hrs	8.0	8.0	8.0	8.0
Duty Time - Day of Accident	5.0	5.0	5.0	5.0
Duty Time - Last 48 Hrs	13.5	13.5	13.5	13.5

Table 2: Summary of Crew Personnel Currency and Duty Information.

	AC	FO	FE	DG
Theatre Check-Out[3]	10 Apr 09	29 Apr 09	25 Apr 09	Completed[4]
Egress training [5]	10 Apr 09	30 Apr 09	22 Apr 09	27 Apr 09
Dustball[6]	24 Jun 09	2 Jul 09		

Table 3: Summary of Currency Requirements for Theatre Qualifications.

[3] The Theatre Check-Out flight includes FOB and dustball landings. No comments were made on the trip report card for either pilot.
[4] The DG theatre check-out form had been filled out but no date was entered.
[5] Egress training is a 12-month recurrent training requirement. All crew members were current at the time of the accident.
[6] Dustball training is a 30-day recurrent training requirement for Afghanistan operations and both pilots were current at the time of the accident.

1.5.2 Aircrew Experience - The AC had approximately 1,000 total flying hrs, with over 760 hrs on the CH146. This level of experience is considered normal for an AC in the Tactical Aviation community. At the time of the accident, the AC had approximately three months of theatre experience. The FO, with over 660 flying hrs on the CH146, was considered an experienced FO. Other pilots described the FO’s flying skills as excellent. The FO had over two months of theatre experience before the accident. The crew of the #2 aircraft was more experienced; that AC had 3,000 flying hrs and his FO had 700 flying hrs.

1.5.3 Aircrew Training – Helicopter training is Phase III of the Canadian Forces (CF) Undergraduate Pilot Training System, which is conducted at 3 CF Flight Training School (3 CFFTS). Upon graduation, pilots proceed to the specific aircraft operational training units (OTU) for type conversion. There is no formal or dedicated training for helicopter operations in a Degraded Visual Environment (DVE), either in whiteout/snowball or brownout/dustball, in the Royal Canadian Air Force (RCAF) either at 3 CFFTS or at the CH146 Griffon OTU. Exposure to snowballs or dustballs is infrequent and often only provided for those students attending the course during the winter months where the chance of entering snowballs is greater. Also, formal briefings on DVE or Obscuring Phenomena at 3 CFFTS are limited. In the Canadian environment, crew exposure to snowballs is relatively common while exposure to dustballs is rare; intense snowballs are more predominant than intense dustballs. To prepare aircrew to deploy to Afghanistan additional training was conducted at Fort Bliss, Texas, where environmental conditions are similar to Afghanistan. Training normally included a total of six flights, including at least two dedicated flights for dustball training. Both pilots conducted this pre-deployment training in 2008 and 2009; however, the FP did not complete the training in 2009, due to aircraft serviceability issues, and only observed a demonstration of the landing technique rather than practiced dustball landings himself. Additionally, the FP did not observe or complete any dustball takeoff techniques. The NFP did practice the dustball landing technique but the serviceability issues also reduced the number of times it was practiced.

1.5.4 Once in Afghanistan, a theatre check-out for all aircrew arriving in theatre was conducted with a seasoned AC. This training comprised of four flights and was recorded on a form that specified the completed manoeuvres and the necessary comments to improve performance. The dustball landing technique was a specific item on the theatre check-out; however, dustball takeoff techniques or takeoffs, requiring an MPTO or ITO, were not. Both pilots had completed their respective theatre check-outs with no comments made on the reporting form, indicating that their performance of a dustball landing was satisfactory and met the standard. The FP had flown only two flights, one day and one night, on his theatre check-out. For the day flight, he flew two to three dustball approaches and departures in light to moderate conditions. For the night flight, the FP was shown two approaches in heavy dustball conditions but these did not terminate with a landing on the ground and resulted with the aircraft overshooting and aborting the approach and landing. The night dustball landings were not conducted. The FP did not conduct any night dustball takeoffs or departures.

1.5.5 Dustball landings were a 30-day currency requirement in theatre and a pilot had to complete at least one dustball landing while at the controls for his aircrew category to remain valid. A pilot not fulfilling this requirement was considered not current and was precluded from any flying until successfully demonstrating a dustball landing to a current and qualified aircraft captain. In the course of normal operations, one dustball landing every 30 days was not difficult to achieve. However, there was no currency or proficiency requirement in theatre for dustball takeoff techniques, including the ITO or the MPTO.

1.6 Aircraft Information

1.6.1 The CH146 Griffon is the Canadian Forces (CF) version of the Bell 412 light utility helicopter and is used mainly for carrying passengers and cargo. In Afghanistan, the CH146 with a standard crew complement of two pilots, one FE and one DG also provided fire support for other aviation assets and troops on the ground.

1.6.2 The accident aircraft was flying with both main cargo doors removed, which is a typical Afghanistan configuration for weight saving considerations. The only cabin seats installed were the transmission side-facing seats, which were occupied by the FE and the DG to operate their respective door guns. The aircraft was equipped with flares, an Infrared Suppression System and two M134D Dillon door guns. The M134D Dillon ammunition container was located in the centre of the cabin, in front of the transmission housing.

1.6.3 The aircraft had accumulated 3,657.5 hrs (based on the last CF335 entry). Engine number one, serial number (S/N) 140239, was installed at 2017.9 airframe hrs (AF hrs) on 25 February 2007 and had accumulated 1946.9 hrs. Engine number two, S/N 140214, was installed at 2017.9 AF hrs on 25 February 2007 and had accumulated 1231.8 hrs. The reduction gear box, S/N TJ0061, was installed at 3041.1 AF hrs and had accumulated 2,440.4 engine hrs. A review of the Servicing Set and Log Set found no overdue inspections, Out of Sequence Inspections (OSI), time expired components, overhauls, modifications or Special Inspections (SI).

1.6.4 Aircraft Certification

1.6.4.1 The Griffon was brought into service in the early-mid 1990's. At the time the Directorate of Technical Airworthiness (DTA) and the Directorate of Technical Airworthiness and Engineering Support (DTAES) did not exist and the CF did not have an airworthiness program that was as developed as it is currently. As a result, virtually all certification approvals were managed and controlled by the Griffon project management office. Since this was predominately an off-the-shelf acquisition, the Aerospace Engineering Test

Establishment (AETE) role was very limited. The CH146 certification was based on the Bell Model 412, which was originally certified under the United States Federal Aviation Administration (FAA) Airworthiness Regulations (FAR) for transport-category helicopters, or FAR Part 29 Airworthiness Standards.[7] The Basis of Certification for the CH146 was the civil FARs but these do not cover employment of the system. The aircraft was transferred to a Canadian Military Airworthiness Type Certificate (CMATC) immediately and prior to operating under military control. The intent was, and always has been, that the aircraft would be operated in accordance with the flight manual including all limitations contained therein.

1.6.4.2 FAR Part 29 prescribes specific airworthiness standards for the issue of type certificates for transport-category rotorcraft (helicopters) defined as Category A or Category B. FARs also lists specific aircraft and rotorcraft equipment, performance and flight characteristics for operations in Visual Flight Conditions[8] (VFC) and Instrument Flight Conditions[9] (IFC). For safe instrument flight, FAR Part 29 establishes a parameter that is unique to helicopters, the Minimum Speed for Instrument Flight[10] (V_{MINI}). The certified Aircraft Flight Manual (AFM) is publication C-12-146-000/MB-002 and is commonly referred to as the “MB” within the CH146 community. The AFM (or the MB) for the Bell Model 412/CH146 states V_{MINI} is 60 knots. This parameter is essential for safe flight as helicopters inherently lack the adequate stability and control characteristics, flight instruments, and situational awareness cues for pilots, to permit safe flight in Instrument Meteorological Conditions[11] (IFC/IMC) below this airspeed.

1.6.4.3 Inadvertent flight into IMC or flight in a DVE such as flight into cloud or flight near the ground where rotor downwash may kick up dust, snow, or spray, is a high risk evolution or flight condition that can be considered an emergency. The severity of these flight conditions can vary depending on several circumstances such as the type of helicopter flown, ambient lighting, duration of flight in, and density of, the obscuring phenomena to name a few. Moving

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[7] FAR Category definitions are available on the FAA website at: http://www.faa.gov/. Rotorcraft with a maximum weight greater than 20,000 pounds and 10 or more passenger seats must be type certificated as Category A rotorcraft. Rotorcraft with a maximum weight of 20,000 pounds or less and nine or less passenger seats may be type certificated as Category B rotorcraft.

[8] Visual Flight Conditions (VFC): Flight conditions in which control of an aircraft may be accomplished solely by visual outside references. B-GA-100-001/AA-000, National Defence Flying Orders, Book 1 of 2, Flight Rules. pg. GL-20/20.

[9] Instrument Flight Conditions (IFC): Flight conditions in which control of an aircraft is required to be maintained solely by reference to aircraft flight instruments (e.g. flight in cloud or night VFR with no discernible horizon).B-GA-100-001/AA-000, National Defence Flying Orders, Book 1 of 2, Flight Rules. pg. GL-12/20.

[10] $V_{MINI:}$ minimum speed for instrument flight. $V_{MAX:}$ maximum velocity.

[11] Instrument Meteorological Conditions (IMC): meteorological conditions expressed in terms of visibility, distance from cloud and ceiling less than the minima specified for visual meteorological conditions. B-GA-100-001/AA-000, National Defence Flying Orders, Book 1 of 2, Flight Rules. pg. GL-12/20.

quickly through the obscuring phenomena requires a generous power margin (power available over power required, as discussed in Annex B); advanced stability-augmentation or autopilot systems or finally; "see through" or "dust-penetrating" systems. However, the effectiveness of these mitigating procedures or systems can be reduced by the specific aircraft model (i.e. an under-powered helicopter with basic flight control, stability or autopilot systems), the lack of adequate systems and the nature of the operating environment (i.e. operating in high, hot and heavy flight regimes).[12]

1.6.4.4 As described in the NATO Research and Technology (RTO) Technical Report TR-HFM-162, Rotary-Wing Brownout Mitigation: Technologies and Training, published in January 2012, there are potential risk mitigating strategies for rotary-wing brownout take-offs and landings and these fall into two broad categories:

> *a) Technology development to overcome the environmental limitation described above under DVE conditions, for example, "see through" or "dust-penetrating" technology, and*
>
> b) *Technology development to overcome the physiological limitation under DVE conditions, for example, provide pertinent information, in an intuitive manner (better landing symbology systems or other sensory displays) to the pilot in order to compensate for the lack of external visual cues*.[13]

1.6.4.5 There is currently no helicopter designed to safely and effectively operates in DVE conditions; some types, both military and civilian, are simply better equipped to do so. Therefore, in keeping with both operating regulations and good airmanship, pilots are responsible to remain vigilant in conditions that may readily deteriorate from Visual Meteorological Conditions[14] (VMC) to IMC where they could inadvertently lose their visual references due to a DVE. When a civil helicopter is operating in conditions below VMC, and where instrument flight is required, it may not be flown at a speed slower than V_{MINI}. According to civil aviation regulations, operations in IMC require that aircraft have been certified (by FAR 29 Airworthiness Standards in this case), that aircrew have been adequately trained, and that certain operating rules are adhered to (FAR 91 General Operations and Flight Rules and others). It is important to stress that neither procedural nor technological mitigations have been adequate to achieve an acceptable level of safety required by civil airworthiness and operating

[12] High, hot and heavy flight regimes is referred to as high altitudes or high density altitudes (HD), hot referring to high OATs and heavy referring to high AUWs.
[13] North Atlantic Treaty Organisation, Research and Technology Organisation, (January 2012), RTO Technical Report TR-HFM-162, ***Rotary-Wing Brownout Mitigation: Technologies and Training***.
[14] Visual Meteorological Conditions (VMC): Meteorological conditions expressed in terms of visibility, distance from cloud and ceiling, equal to or better than specified minima. B-GA-100-001/AA-000, National Defence Flying Orders, Book 1 of 2, Flight Rules. pg. GL-20/20.

regulations. As such, the total set of airworthiness and operating regulations for civil helicopters such as the Bell Model 412 prohibit flight slower than V_{MINI} when taking off, or landing in conditions below VMC or in DVE/IMC.

1.6.4.6 Many military missions would not be possible if these same restrictions were imposed on military helicopters. For the CF, military helicopter operations are often exposed to DVE conditions or where VMC may readily deteriorate to IMC and many of these are at low speed, i.e., below V_{MINI}, as was the case with the accident aircraft. The CF has implemented training and flight procedures to help mitigate the risks and to focus on minimizing the duration in which a helicopter is exposed to these high-risk conditions. Mitigating measures are based on specific procedures described in the CH146 Standard Manoeuvre Manual (SMM) and techniques which are taught during pilot training. These procedures reduce the time in which the helicopter is flown in instrument conditions below V_{MINI} by effecting as quick a transition through the DVE conditions as possible. By minimizing the time spent within the obscuring phenomena, the time in which the aircraft may wander off course and/or the pilot becomes disoriented is reduced, thereby reducing the likelihood of a rollover or a collision with either the ground or an object.

1.6.4.7 On the technological side, some stability-augmentation and autopilot systems have provided mitigation for select helicopter models and these measures have continued to help reduce the risk for military operations. However, research and development of adequate systems, as proposed in the NATO paper, have not yet matured to a level for operational use. Therefore, none of the CF helicopters, including the CH146, have such see-through or dust-penetrating technology systems or systems using landing symbology or sensory displays for safe flight in a DVE below V_{MINI}. While the CH146 is equipped with some stability-augmentation and autopilot systems, neither of the current CH146 systems, handling qualities or flight instruments are designed, certified, approved, intended, nor precise enough to allow aircrew to allow safe flight in a DVE below V_{MINI}. Also, the helicopter’s inherent hover instability, combined with this lack of advanced instrumentation and awareness cues, do not allow for safe flight in a DVE below $V_{MINI.}$

1.6.5 Aircraft Flight Manual (AFM)

1.6.5.1 The definitions and differences between an AFM and an Aircraft Operating Instructions (AOI) are not listed in the current version of the C-05-005-001/AG-001, Technical Airworthiness Manual (TAM). The Technical Airworthiness Authority (TAA) has identified this discrepancy and is drafting a proposal to the next amendment of the TAM that will provide definitions and descriptions of an AFM, an AOI and SMM as provided in the footnote below.[15]

[15] The following are definitions that are proposed for the next amendment of the CF Technical Airworthiness Manual:

The CH146 had a civil AFM for the Bell Model 412 approved by the FAA. By adding additional information, the Canadian Forces Technical Order (CFTO) for the CH146 was developed from the civil AFM. While for other CF fleets this type of document is often called the AOI, the CH146 CFTO was titled "Flight Manual" and no CH146 AOI was created. This CFTO is specifically referenced on the civil Type Certificate Data Sheet for the Bell Model 412CF, the CH146, as the approved AFM. The difference between an AFM and an AOI is that while Technical Airworthiness Data (TAWD) or performance charts are included in both documents, the AFM provides the charts with only minor explanations on their use. Specific details on how to use the charts for mission-oriented purposes are normally contained in the AOIs.

1.6.5.2 The AFM is an integral part of the aircraft airworthiness certification process and details pertinent information under Limitations, Normal Procedures, Performance and Operating Information for use by the aircrew. The version of the AFM in use at the time of the accident was Change (Ch) 2 dated 2009-02-20. The AFM contains charts depicting limitations in Section 1 - Limitations. These are limits imposed by the manufacturer and/or regulator to ensure safe operation and they shall not be exceeded. Section 4 - Performance includes charts that determine aircraft performance guaranteed by Minimum Specification[16] (Min

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TECHNICAL AIRWORTHINESS DATA (TAWD) – That portion of the information and data contained in the Type Record that is required to safely operate the aircraft throughout its approved envelope, which comprises the TAWD for an aircraft type. An applicant for an aircraft Type Certificate must submit to the TAA for approval a Flight Manual that contains this TAWD.

AIRCRAFT FLIGHT MANUAL (AFM) – The AFM is an operational document that contains the TAWD along with additional non-TAA-Approved data and information. The AFM TAWD shall be identified, clearly distinguished, and preferably segregated from the non-approved data.

AIRCRAFT OPERATING INSTRUCTIONS (AOI) – The AOI is the operating manual provided by the aircraft operator to aircrews. It is normally issued and approved by the operating authority. In general, the AOI expands upon the AFM by including supplementary and mission-oriented information that is not included in the basic AFM. TAWD reproduced in the AOI shall be consistent with that appearing in the AFM. In some cases, the AFM contains sufficient supplementary and mission-oriented information to serve as the AOI directly. For many legacy aircraft, the AOI is the sole document and it includes all the TAWD. When the AOI is the sole document, the TAWD should be clearly identified as TAA-approved information and preferably segregated. In this case, the TAWD within the AOI constitutes the AFM.

The STANDARD MANOEUVRE MANUAL (SMM) is a document produced by the aircraft operator under the authority of the OAA to provide aircrews with guidance regarding the manner in which the aircraft is to be flown to accomplish its intended missions. A SMM is produced for each aircraft operated by the CF. The TAA provides no oversight of the SMM. A statement in the foreword of each SMM states that, in case of any disagreement between the SMM and the TAA approved AFM (or AOI), the TAA-approved document has precedence. TAWD appearing in any SMM, aircraft operating manual or checklist must be consistent with the TAWD appearing in the AFM.

[16] See also Annex B, paragraph b. Aircraft engines performing at Min Spec or above meet the certification requirements and are considered serviceable. The engine may exceed this

Spec) performance. The performance levels found in Section 4 are not limitations as specified in Section 1 and there are no directions within Section 4 restricting aircrew from exceeding these parameters. Section 8 - Operational Information includes additional information for operational flight planning and may at times depict aircraft performance beyond the limitations set in Section 1. Terms and definitions pertaining to aircraft performance are listed in Annex B. The AFM Ch 2 Section 1 limitations that are pertinent to this accident for twin-engine operations are copied below:

INTERTURBINE TEMPERATURE (ITT)

TWIN ENGINE OPERATION

Continuous	300 to 810°C
Maximum continuous	810°C
Maximum transient Do not exceed 5 seconds above 810°C	940°C
Maximum for starting Do not exceed 2 seconds above 960°C	1090°C

CAUTION

INTENTIONAL USE OF ITT ABOVE 810°C IS PROHIBITED DURING NORMAL OPERATIONS EXCEPT DURING START.

1-18. MAST TORQUE

TWIN ENGINE OPERATION

Maximum with airspeed above 105 KIAS	81%
Takeoff (5 minutes)	81 to 100%
Maximum with airspeed up to 105 KIAS (5 minutes)	100%

CAUTION

INTENTIONAL USE OF MAST TORQUE ABOVE 100% IS PROHIBITED.

WHEN OPERATING NEAR MAXIMUM MAST TORQUE LIMIT, INADVERTENT OVERTORQUE MAY OCCUR DURING MANEUVERING FLIGHT CONDITIONS INVOLVING TURNS AND/OR NOSE DOWN ATTITUDE CHANGES. DECREASE POWER TO 90% MAST TORQUE PRIOR TO MANEUVERING HELICOPTER.

Figure 2: ITT limits (left column), Mast Torque limits (right column).[17]

1.6.5.3 The FARs in place at the time the CH146 was certified only required IGE hover limitations be identified in Section 1. OGE charts (Weight-Altitude-Temperature (WAT) or Hover Ceiling) were not a FAR requirement at the time the CH146 was certified but were added as requirements in later amendments to the FARs.

1.6.5.4 Section 1 - Weight-Altitude-Temperature (WAT) Charts: The AFM contains WAT charts for operations In Ground Effect (IGE). IGE WAT charts are required by certification and are contained in Section 1. The IGE WAT chart ***Figure 1-1 (Weight-Altitude-Temperature limitations for takeoff, landing and in-ground-effect maneuvers, all wind azimuths, 10 passengers or more)***, (Annex C: pg. 1/6) is used to determine the aircraft maximum allowable weight limit and maximum Density Altitude (HD) for takeoff, landing and IGE hover

performance, but is not considered serviceable if it is producing less than the minimum specified performance.

[17] C-12-146-000/MB-002, Ch 2 dated 2009-02-20, pg 1-7 and 1-8.

operations. It is also referenced when using the Height - Velocity diagram. A very critical note on ***Figure 1-1*** states:

> NOTE: ALLOWABLE GW OBTAINED FROM THIS CHART MAY EXCEED CONTINUOUS HOVER CAPABILTY UNDER CERTAIN AMBIENT CONDITIONS. REFER TO HOVER CEILING CHARTS IN SECTION 4.

Figure 3: WAT chart *Figure 1-1* note.

1.6.5.5 IGE WAT chart ***Figure 1-1A (Weight-Altitude-Temperature limitations for takeoff, landing and in-ground-effect maneuvers, wind from -45^{o} to +45^{o} azimuths, 9 passengers or less)*** (Annex C: pg. 2/6) was also available but it did not include the note directing the reader to the Hover Ceiling charts in Section 4. There is no direction provided in Section 1 on how to use this chart. This chart does not fully meet the FAR requirements (as defined in para 1.6.5.3.) for limitations since it only represented ITT limited performance and did not include maximum AUW limitations or maximum density altitude limits.

1.6.5.6 Section 4 - Hover Ceiling IGE/OGE Charts: The various Hover Ceiling IGE/OGE charts found in Section 4 (of which two examples are at Annex C: pg. 5/6) depict the maximum allowable aircraft gross weight (GW) for hovering IGE or OGE at all pressure altitudes (HP) and outside air temperature (OAT) conditions. Conversely, the hover ceiling altitude can be determined for any given GW. While the OGE Hover Ceiling charts were not a FAR requirement at the time of CH146 certification, they were provided by the OEM for flight planning purposes. The Hover Ceiling charts in combination with the ***Figure 4-3 Critical Relative Wind Azimuths chart*** determine, among other factors, a maximum GW for which satisfactory cyclic and directional control (flight control authority) is available while not exceeding other engine parameters. Exceeding WAT or Hover Ceiling weights (i.e. too heavy for a given altitude or temperature) means that there is a potential risk of reaching a variety of limits. These various limits, dependant on aircraft type and environmental conditions, could include rotor aerodynamic performance, flight control authority (where inputs are limited by a physical control stop or effective aircraft control is hampered), height-velocity limitations, transmission limits and, engine limits (ITT or N1). Weight limits derived from the WAT or Hover Ceiling charts do not determine or calculate maximum aircraft performance, since these are based on Min Spec engine performance. When the aircraft is operated with engines that perform better than Min Spec, the power available will be increased while the presence of a positive or negative wind vector will reduce or increase power required respectively.

1.6.5.7 Section 8 - OGE WAT Charts: At the time of certification for Bell Model 412 these performance charts were required for FAR Part 29 Category A performance certification.[18] As the Bell Model 412 was certified under FAR Part

[18] FAR Category definitions are available on the FAA website at: http://www.faa.gov/. Rotorcraft with a maximum weight greater than 20,000 pounds and 10 or more passenger seats must be type certificated as Category A rotorcraft. Rotorcraft with a maximum weight of 20,000 pounds or less and nine or less passenger seats may be type certificated as Category B rotorcraft.

29, Category B performance certification, the OGE hover performance information was not required. Neither of these charts met the FAR requirements for Section 1 limitations nor did the data contained therein match the data in the Section 4 hover ceiling charts for IGE or OGE. The inclusion of these charts in the AFM was optional for the Original Equipment Manufacturer (OEM) and DND. ***Figure 1-1A*** was originally included in Section 8 (***Figure 8-13***) as operational information, but was moved to Section 1 as part of a Temporary Revision and then fully incorporated as part of CH2. In Dec 07, 1 Canadian Air Division (1 Cdn Air Div) message UNCLAS APT RDNS 146, SUBJ: CH146 ALL-UP WEIGHT LIMITS CLARIFICATION approved the move of ***Figure 8-13*** from Section 8 Operational Information to become a limit in Section 1 Limitations. This expanded the CH146 operating envelope and allowed improved performance planning.

1.6.5.8 Section 8 - Cruise Performance Charts: The AFM cruise performance charts found in Section 8, specifically **Figure 8-1 (sheets 1 through 24)**, present "engine torque available, fuel flow, indicated airspeed, true airspeed, and standard drag configuration, for operational GW hover torque required, maximum endurance torque required and best range, engine and mechanical limit speeds"[19] (Annex D). These Section 8 charts consider the HP, ambient temperature and aircraft weight and can be used to derive a torque value achievable or available without exceeding any engine parameters (ITT or N1). The 24 sheets of **Figure 8-1** are provided from Sea Level to 14,000 ft in 2,000 ft altitude increments and interpolation is required for altitudes that are not charted. These were the charts that made reference to power available and mast torque values at zero airspeed. A review of these charts found that in addition to being complex, confusing and difficult to use, the sheer number and amount of charts to be carried and referred to in-flight made it very difficult to calculate aircraft performance values while conducting operations.

1.6.5.9 Section 8 - Hover Torque Required charts: The torque required to hover (power required) is obtained from the respective IGE and OGE Hover Torque Required charts (Annex E) also found in Section 8.

1.6.6 Aircraft Weight Information

1.6.6.1 Between the morning and afternoon missions both aircraft had refuelled at the Forward Arming and Refuelling Point (FARP). The accident aircraft refuelled with 2,050 lbs of jet fuel while the #2 aircraft refuelled with 1,840 lbs of jet fuel. At the time of the afternoon takeoff from KAF, the accident aircraft weighed approximately 11,500 lbs, which included 1,810 lbs of fuel. On takeoff out of the FOB the reduced fuel quantity was noted to be approximately 1,300 lbs. However, with the two passengers then onboard, the aircraft GW was

[19] C-12-146-000/MB, Ch 2 dated 2009-02-20, pg 8-3, paragraph 8-6.

estimated to be 11,520 lbs.[20] The #2 aircraft weighed approximately 11,000 to 11,200 lbs at the time of the afternoon takeoff from KAF. Similarly, for the takeoff from the FOB, with consideration for the reduced fuel quantity and added passengers, the #2 aircraft weight was estimated to be near 11,200 lbs. Given comparable fuel consumption rates for both aircraft for the flight time from the refuelling point to the ramp, the start, the transit from KAF to the FOB and the similar passenger weights, it is estimated that the accident aircraft weighed 300 to 500 lbs more than the #2 aircraft.

CH146434	**Fuel Added**	**AUW**
KAF	2,050 lbs	11,500 lbs
FOB	0	11,520 lbs
CH146414 (#2)		
KAF	1,840 lbs	11,200 lbs
FOB	0	11,200 lbs

Table 4: Aircraft fuel and weight information.

1.6.7 Engine Fire Warning System

1.6.7.1 In the event of an engine compartment fire, heat causes the thermistor material in the fire detector elements to decrease in resistance value, which allows an electrical current to then flow and illuminate the associated FIRE PULL warning light. There are two separate engine fire-extinguishing systems, main and reserve. The system components include the main and reserve fire extinguisher agent bottles, a FIRE EXT activation switch with MAIN, OFF, and RESERVE positions located between the engine FIRE PULL handles and separate electrical power systems for each bottle. The FIRE PULL handle contains the warning lights that are illuminated by the detection system. Pulling a FIRE PULL handle arms both fire extinguisher bottles and selects the engine into which the agent is released. It also closes the selected engine's fuel valve, the particle separator door, and the bleed air ports on both engines. Selecting the FIRE EXT to MAIN or RESERVE will then fire the respective bottle to the selected engine (right, left or both). The FP pulled both fire handles, however, the fire extinguishing activation switches were not activated, the throttles were left open, and the battery bus switches were left in the ON position.

1.7 Meteorological Information

1.7.1 There was no meteorological station at the FOB. METARs (aviation meteorological reports) were issued from Qalat Airfield and KAF. The weather forecast consisted of a Graphical Area Forecast (GFA). There were very few clouds. Although the winds at the FOB were noted to be light and variable as assessed by the crew, they were strong enough to warrant a change of the

[20] The CH146 community has predetermined estimates for passenger weights depending on an individual soldier's role and equipment being carried. In this case 250 lbs for each passenger was assessed, which included personal weapons, ammunition and personal protective equipment.

intended approach path into the landing zone. Table 5 presents the relevant OAT, HP and HD for the morning and afternoon flights.

Location / Time of flight	**OAT**	**HP**	**HD**[21]
KAF - elevation 3,310 ft			
Morning flight	37ºC	3,470 ft	7,000 ft
Afternoon Flight	42ºC	3,520 ft	7,500 ft
Location / Time of flight	**OAT**	**HP**	**HD**
FOB - elevation 4,595 ft			
Morning flight	35ºC	4,625 ft	7,900 ft
Afternoon Flight	39ºC	4,675 ft	8,500 ft

Table 5: OAT, HP and HD for the morning and afternoon flights.

1.8 Aids to Navigation

Not applicable.

1.9 Communications

1.9.1 Air-ground communications between the accident AC and the #2 aircraft circling above were made using a Combat Search and Rescue Radio. The request for medical evacuation was sent to KAF by the #2 aircraft who provided relay communications from the FOB to Canadian Helicopter Force (Afghanistan) [CHF(A)] during the initial emergency response activities. A section of two CH146s later relieved the #2 aircraft on station so that #2 could return to KAF for fuel.

1.10 Aerodrome Information

1.10.1 There were a great number of FOBs in Afghanistan. In the conduct of their assigned missions, Canadian aircrew were required to fly to several FOBs, many of which were not, as in this case, under Canadian control. This foreign controlled FOB measured approximately 450 ft wide by 420 ft long. The FOB entrance was located approximately in the middle of the northern wall. In the middle of the FOB was an obstacle surrounded by a HESCO barrier. A helicopter landing site was marked by rocks placed in a circle on the west side of the FOB. There were no other markings for the helicopter landing site. (See Figure 1, paragraph 1.4)

1.10.2 The day of the accident was the first time Canadian helicopter aircrew had ever flown into that specific FOB. The crew prepared for their mission using an aerial picture of the FOB in conjunction with a written description of the landing site. For the morning insertion, the helicopters landed in the designated

[21] The density altitude was calculated using the chart found in the CH146 AFM, Figure 4-2 Density Altitude (HD), at page 4-7. Accessed and reconfirmed via the IETM 12 Sep 12.

landing site. During the afternoon extraction mission, due to wind and obstacle considerations, the aircrew landed in the FOB but at an alternate landing site.

1.10.3 Dust suppression methodologies varied greatly from FOB to FOB and were based on available resources, costs, the individual nations responsible for the FOB and logistical challenges. There were no standards published for dust suppression within the Afghanistan theatre of operations. The FOBs under Canadian control had gravel laid on the helicopter landing site to limit the amount of dust that would be disturbed by the helicopter downwash on takeoff and landing. This FOB was considered austere and dust suppression methods were not available or employed.

1.10.4 Fire suppression capabilities also varied from FOB to FOB. The accident FOB had only hand-held fire extinguishers available, all of which were used in the attempt to extinguish the post-crash fire. For the same reasons affecting dust suppression methodologies, there were no standards published regarding fire suppression within the Afghanistan theatre of operations.

1.11 Flight Recorders

1.11.1 Cockpit Voice and Flight Data Recorder

1.11.1.1 The CH146 is equipped with a Penny and Giles solid state, Type 2000, combined Cockpit Voice and Flight Data Recorder (CVFDR) encapsulated within the same protective case. The CVFDR was retrieved from the debris after the post-crash fire was extinguished.

1.11.1.2 Preliminary inspection of the CVFDR revealed a breach of the unit’s integrity and severe localized heat damage. The recorder was sent to the National Research Council (NRC) Flight Data Recorder Replay Center in Ottawa where it was confirmed that the unit sustained fire and heat damage (Annex A: Photo 4) that significantly exceeded its design limits. However, NRC, in conjunction with the CVFDR manufacturer, was able to recover the majority of the stored data by placing the accident CVFDR memory chips into a serviceable CVFDR.

1.11.1.3 Since the CVFDR does not record Qm, NRC and AETE each developed mathematical methods to estimate Qm from the combined engine torques. In the 2009 to 2011 timeframe, and based on the available data from the CH146 Weapon System Manager (WSM), AETE and the NRC, the maximum Qm used by the accident aircraft and the #2 aircraft was estimated to be 91% and 92% respectively. Since then, the WSM and AETE have worked together and conducted additional flight tests to further refine CH146 aircraft performance. This data and other selected FDR data is explained in Section 2 and presented in graphical format in Annex F.

1.11.2 Health and Usage Monitoring System

1.11.2.1 The CH146 is equipped with a Health and Usage Monitoring System (HUMS). The HUMS recorder is not crashworthy and was destroyed in the post-crash fire however the HUMS data file from the previous download and the HUMS data from the #2 aircraft were examined for comparative analysis. HUMS data from the #2 aircraft recorded a ITT exceedences greater than 810ºC for longer than 5 seconds on both engines at values up to 850ºC (40 degrees in excess of the maximum continuous limit) during the morning and afternoon takeoffs from the FOB. Actual recorded values are depicted in Section 2, paragraph 2.7.11, Table 6.

1.11.2.2 HUMS data is regularly downloaded and analysed by the CH146 Technical Authority for maintenance purposes. From December 2008 to November 2009, collected HUMS data recorded a total of 1,322 exceedences in Afghanistan. These included main rotor (Nr), gas generator (Ng), and power turbine (Nf) overspeeds, exceedences with mast torque and 1,120 ITT exceedences in which the ITT was between 810ºC and 940ºC for more than five seconds.

1.12 Wreckage and Impact Information

1.12.1 The barrier where the aircraft impacted was located approximately 95 ft away from the takeoff point and located at the one to two o’clock position relative to the nose of the aircraft. The impact point was approximately four to five ft high on the inside wall of the barrier (Annex A: Photo 2). Two distinct main rotor blade strikes were found on the outside wall of the barrier, cutting at approximately a 45º angle from the horizontal (Annex A: Photo 3). One of the main rotor blades was severed just inside the blade attachment point and lodged itself into the barrier opposite the FOB entrance. One of the oil cooler inlet cowlings was thrown over the barrier opposite the FOB entrance when it was struck by a main rotor blade. The right pilot windscreen shattered on impact with either the barrier or the ground. Otherwise, the aircraft was relatively intact when it came to rest on its right side (Annex A: Photo 5).

1.12.2 The post-crash fire destroyed much of the physical evidence (Annex A: Photo 6). The wreckage was further disturbed during the fire fighting effort and subsequent recovery of the bodies.

1.13 Medical

1.13.1 The aircrew medicals were valid at the time of the accident.

1.13.2 The survivors were medically evacuated from the FOB to the Role 3 medical facility[22] at KAF for assessment and treatment. The Canadian

[22] Role 3 is the specialized medical facility that treats all critically injured personnel at KAF.

passenger was transferred to Landstuhl Regional Medical Centre in Germany and medically repatriated to Canada.

1.13.3 As required by flying orders, blood and urine samples were taken from the two pilots and sent to the Armed Forces Institute of Pathology (AFIP) in Washington, DC for analysis. The toxicology results were negative.

1.13.4 The remains of the deceased were recovered from the wreckage by FOB personnel prior to the arrival of Flight Safety personnel. Their location in the wreckage was not documented prior to their removal. The remains were transported by helicopter to KAF mortuary affairs for positive identification.

1.13.5 Causes of Death

1.13.5.1 The forces of impact were likely survivable and the causes of death were directly related to the post-crash fire. As reported by the official pathologists and coroners’ reports, the cause of death for the FE was inhalation of smoke and fire gases. The cause of death for the DG was inhalation of fire gases with thoraco-abdominal trauma as a contributing factor. The cause of death for the coalition soldier was multiple injuries and inhalation of fire fumes.

1.14 Fire, Explosives Devices, and Munitions

1.14.1 Fire

1.14.1.1 The aircraft caught fire immediately after coming to rest on its side. The FDR data indicated that the number Two Engine Fire Warning light illuminated, followed immediately by the number One Engine Fire Warning light. The pilots recalled seeing the illumination of these lights and having pulled the FIRE PULL handles. The fire was first observed in the rear cabin in the vicinity of the number two hydraulic pump near the ceiling of the cabin in front of the transmission housing. Both hydraulic and fuel lines are routed through the transmission housing. Hydraulic fluid (MIL-PRF-5606 type) is extremely flammable, as is aviation turbine fuel (JP-8 or F-34 type). Aviation turbine fuel vapours are heavier than air and may travel a considerable distance to sources of ignition and then flash back. The precise cause of the fire or the source of ignition could not be determined. The fire intensity was such that it prevented the pilots from assisting personnel in the rear cabin area and melted or reduced to ash nearly all parts of the aircraft forward of the tail section (Annex A: Photo 6).

1.14.1.2 Once the personnel from the FOB realized that an accident had occurred and that the aircraft had caught fire, many of them started bringing portable fire extinguishers from the FOB stocks. All of the available fire extinguishers were portable types and every fire extinguisher was discharged in an attempt to put out the fire. The #2 aircraft radioed back to KAF and requested a high capacity deployable fire extinguisher; however, the aircraft burned for over an hour before the unit arrived at the FOB.

1.14.2 Explosive Devices

1.14.2.1 Two Cartridge Actuated Devices for the engine fire bottles were installed on the aircraft. These were not found and likely were destroyed in the post-crash fire.

1.14.3 Munitions

1.14.3.1 M134D Dillon Gun: There were two M134D machine guns installed on the aircraft. The aircraft servicing set, form CF338 - Aircraft Armament State, indicated there were 8300 rounds of 7.62 mm on board. Most of the M134D Dillon ammunition detonated in the post-crash fire.

1.14.3.2 ALE 29A Dispenser: The form CF338 indicated there were 30 ASD3627 flares installed in the left-hand flare dispenser and 27 installed in the right-hand dispenser prior to the mission. The post-crash fire detonated all but one flare.

1.14.3.3 Personal Weapons: Each pilot carried a 9mm pistol and a C7 rifle. The FE and the DG each carried a C7 rifle. The total ammunition count was not recorded in the aircraft servicing set. Most of the personal weapon ammunition carried in the aircraft detonated in the post-crash fire.

1.14.3.4 Miscellaneous Armament: According to the CF338, there were four smoke grenades on board. These were not found and likely detonated in the post-crash fire.

1.15 Survival Aspects

1.15.1 Cabin seating configuration

1.15.1.1 The CH146 AFM establishes the standard and approved seating configurations. At the time of the accident, there were 14 approved configuration changes listed that were deemed most typically encountered to satisfy the majority of training and operational requirements. These included the standard configuration and configuration changes for operations with the door guns, litter, parachute or rappel operations, and transport of Very Important Persons. At the unit level, deviations to the standard configuration or the approved configuration changes were authorized by opening form CF349 in the aircraft servicing set. A review of the aircraft servicing set found no anomalies however a review of the AFM, the SMM and CHF(A) flying orders found that no specific direction or authorization for the use of seats or lap belts existed. The investigation found no documentation provided by higher headquarters approving or rejecting the proper selection of a specific configuration or the specific use of seats or lap belts. There were four personnel in the rear cabin: the FE, the DG, and two passengers. The FE and DG were seated on their respective transmission side-facing seat and manning their door gun with the FE on the right side and the DG on the left side. The passengers were not securely seated in approved seats with approved lap belts. The Canadian passenger was seated on the floor of the left side of the cabin with both legs hanging over the side. His seatbelt was attached and secured to the floor mounted cargo tie-down fittings. The Coalition soldier was similarly seated on the floor, but on the right side of the cabin. During the morning flight into the FOB he had been seated at the door with his legs crossed and inside the cabin. Conversation between the two passengers between flights focussed on the uncomfortable seating arrangements and possible alternatives. It was pointed out to the Coalition soldier that one alternative was to sit with his legs over the side.

1.15.2 Crash Survivability

1.15.2.1 The deceleration forces were a combination of forces along the G(x) (fore/aft) axis and G(y) (lateral) axis. The initial impact with the barrier was at low velocity and was survivable. The liveable space of the aircraft remained mostly unchanged (Annex A: Photo 5). The right door gun and pintle mount may have protruded into the cabin space at the FE station as the aircraft came to rest on its right side. Due to the extent of fire damage, the post-impact position of the door gun and pintle mount could not be determined.

1.15.3 Aviation Life Support Equipment

1.15.3.1 The Aviation Life Support Equipment (ALSE) of all four aircrew was recorded as serviceable at the time of the accident.

1.15.3.2 There were two types of aircrew helmets in service use for CH146 aircrew: the SPH-5 and the HGU56P. The HGU56P helmet could be fitted with a Maxillo Facial Shield (MFS) while the SPH-5 could not. The MFS was a protective shield worn below the helmet visor and extended just below the chin level. Its intent was to protect the eyes and face of the cabin crew from flying dust and debris. There were dust protective goggles approved for use as well. Both the MFS and the dust protective goggles were approved for use in February 2009.[23]

1.15.3.3 The HGU56P helmets and the MSV98HC survival vests of the two pilots were undamaged in the accident. The remaining crew members' ALSE was destroyed in the post-crash fire.

1.15.3.4 CHF(A) FEs and DGs were using a prototype tactical aviation quick release harness in Afghanistan. The 30 Mk 1 Crewman Restraint Harnesses (CRH) delivered to theatre were under Operational Test and Evaluation (OT&E) following a recommendation made after the 13 July 2006 Cormorant CH149914 accident. The CRH incorporates the Crewman Restraint Release (CRR) system with the Crewman Restraint Tether (CRT). One end of the CRT (often referred to as a Monkey Tail) is attached to a strong point on the aircraft and the other end is

[23] UNCLAS COMD 571, COMD auth for MFS, CEP, and aircrew eye protection goggles, 231818Z Feb 09.

attached to the CRR tail on the back of the harness. The CRT can be adjusted from 16 inches to nine ft. The SMM states that the Monkey Tail should be adjusted in such a way as to prevent no more than one third of a person's body from projecting beyond the door opening. The CRR design includes an emergency release mechanism located in front of the left shoulder which can be activated using a single hand. When the emergency release process has been completed the CRR tail is released from the harness freeing the wearer from the CRT still attached to the aircraft. The two attachment hooks (one at each end of the CRT) have also been redesigned to allow single-hand release.

1.15.4 Search and Rescue

1.15.4.1 Before evacuating the aircraft, the two pilots looked back in the rear cabin area to assess the situation. The post-crash fire had already started and the cabin was reported as very dark, possibly due to smoke and/or dust from the rotor wash and/or impact with the ground. The pilots could not see anybody in the rear cabin but were able to exit the aircraft through the right shattered windscreen. The Canadian passenger, despite serious injuries, followed the pilots through the same exit. Immediately after egress, the pilots attempted to provide assistance to the personnel still inside the helicopter, but were precluded from doing so by the intensity of the post-crash fire. FOB personnel could not assist in rescue activities due to the explosive cook-off of ammunition and intensity of the post-crash fire.

1.16 Test and Research Activities

1.16.1 Fluid Sampling

1.16.1.1 The post-crash fire consumed all possible sources of fluid samples from the accident aircraft. A fuel sample was taken from the #2 aircraft as it refuelled from the same facility at approximately the same time as the accident aircraft. Engine oil, transmission oil, and hydraulic fluid samples were taken from the pump carts that last serviced the accident aircraft. All samples were sent to the Quality Engineering and Test Establishment (QETE) on 15 July 2009 and were determined to be authorized for the CH146 and of good quality.

1.16.2 Publications Review

1.16.2.1 DTAES conducted a review of the CH146 AFM, C-12-146-000/MB-002 on behalf of the TAA. DTAES' post-accident findings regarding the AFM and the performance charts detailed in the DTAES technical note 75-09-15 indicated several discrepancies and errors including the validity of various hover OGE (HOGE) and hover IGE (HIGE) charts. DTAES consulted with the OEM who supported these findings but this was testimonial in nature as no formal documentation such as certification reports were provided for review. The technical note was completed in October 2009. The technical note is included as Annex G.

1.16.2.2 As a result of this review, 1 Cdn Air Div released UNCLAS COMD 628, PUBLICATION AMENDMENT: CH146 FLIGHT MANUAL dated 051658Z NOV 09 and authorized the removal or correction of several charts. Specifically;

a. On ***Figure 1-1***, the indication of 10 passengers or more was deleted allowing for the use of this chart regardless of passenger configuration;

b. As WAT charts were no longer to be used as the basis for performance planning, ***Figures 1-1A, 8-11, 8-12*** and ***8-13*** were removed entirely; and

c. ***Figure 4-4*** (sheets 4, 5, 9, and 10) were removed entirely as these charts referred to the standard Bell heater. (Again, this heater was not installed on the CH146 which has the upgraded winterization heater instead. In this case ***Figure 4-4*** sheets 6 and 11 apply.)

1.16.2.3 It is important to note that the title change of ***Figure 1-1*** and the removal of ***Figure 1-1A*** from the AFM reversed the changes that were introduced by AFM Ch 2. Further, ***Figures 8-11 to 8-13*** were removed because they were viewed as incomplete, potentially misleading and of questionable validity.

1.16.2.4 The DTAES technical note indicated that Ch 2 did not receive TAA approval. The Operational Airworthiness message approving Ch 2 was a joint Operational Airworthiness Authority (OAA) and Senior Design Engineer (SDE) message. What could not be determined was the level of review that was undertaken by the SDE or TAA staff prior to the release of this message. TAA staff was not involved in the approval that was provided for the Ch 2 amendment to the AFM. Questions arose concerning the approval authority provided to the SDE. The investigation found issues that caused a lack of clarity on the requirement for TAA review and approval of flight manual amendments, and led the SDE to believe that approval was within the SDE's scope of delegated airworthiness authority. It is not to suggest that an SDE operated beyond their scope, but rather the investigation identified factors that confused the boundaries of that scope and the roles and responsibilities of the WSM, DTAES, and Air Force staffs in regards to flight manual amendments. A review of TAA and Director General Aerospace Equipment Program Management (DGAEPM) processes has indicated that no formal review and approval processes were in place at the time of the accident. At the time of the Ch 2 approval, the CH146 WSM utilized the Aircraft Modification Approval Form (AMAF) process to manage changes to the AFM. No AMAF could be found for this Ch 2. Since the accident, TAA/DGAEPM processes for amendments, review and approval of publications of CF aircraft have been published. This is intended to prevent any further changes to the CH146 AFM, or any other CF aircraft AFM, without appropriate review by both TAA and OAA staff.

1.17 Organizational and Management Information

1.17.1 Deployment of the CH146 into Afghanistan

1.17.1.1 The idea of deploying the CH146 into Afghanistan was first conceived in 2003. In 2004-2005, the Chief of the Air Staff (CAS), now called Commander of the Royal Canadian Air Force (Comd RCAF) and Chief of the Air Force (C Air Force), tasked several staff checks to 1 Cdn Air Div to review and compare CH124 Sea King and CH146 Griffon performance capabilities. In 2007, the Air Force renewed its efforts to convince the chain of command to approve the CH146 for deployment to Afghanistan. The role of the CH146 was to gather intelligence, conduct surveillance, reconnaissance and limited tactical airlift missions. The main issues were the aircraft performance limitations in the high, hot and heavy flight regimes and the limited on board self-defence/survivability equipment that elevated the risk for certain missions in Afghanistan.

1.17.1.2 In January 2008, the Independent Panel on Canada's Future Role in Afghanistan, commonly referred to as the Manley Report, was made public and recommended that Canada should continue with its responsibility for security, including its combat role in Afghanistan. One key aspect was the recommendation to secure medium helicopter lift capacity before February 2009. The RCAF proceeded with the acquisition of six CH147D Chinook helicopters and by mid-2008, the CH146 deployment to Afghanistan was revisited and now included the Chinook escort role to the CH146's list of potential roles in Afghanistan. While deployment preparations and training for the Chinook deployment started shortly after the release of the Manley Report, the request and decision to deploy the CH146 to Afghanistan was not approved until later in 2008. In approving the deployment of the CH146, the chain of command had the full expectation that the aircraft would be operated within its known limitations.

1.17.2 CH146 Statement of Operating Intent[24] (SOI)

1.17.2.1 The accident mission type was included within the Tactical Helicopter Missions listed in the CH146 Griffon SOI version 1.0, 19 September 2008. Section 2 SYSTEM OPERATION, paragraph 2.3 Environment, states that the "*CH146 will be expected to conduct mission throughout broad and complex physical, meteorological, electromagnetic and threat environments."* In 2.3.1 it goes on to state that the "*CH146 shall be expected to operate at altitudes from*

[24] As defined in the C-05-005-001/AG-001, TECHNICAL AIRWORTHINESS MANUAL (TAM), Ch/Mod 5 - 2007-07-28: *The SOI is developed by the intended operators of the aircraft and approved by the OAA prior to submission to the TAA. In general, the SOI identifies the intended roles, missions, tasks and usage of an aircraft type in sufficient detail to permit the engineering analysis and assessment of the proposed type design and allow selection of appropriate airworthiness standards. It should be noted that the operating environment and specific usage of an aircraft are fundamental to establishing and maintaining airworthiness. To assure continuing airworthiness, the SOI must be maintained and revised as necessary throughout the service life of the aircraft to reflect any changes to the roles, missions, tasks, operational usage and/or environment.*

sea level up to 10,000 feet above sea level (ASL)…. the CH146 shall complete missions from austere and unprepared locations and under conditions of blowing and/or re-circulating dust, sand, snow water and debris." In paragraph 2.3.2.1 it also indicates *"the climates in which CH146 operates range from the snow and intense cold of the arctic, to turbulent, high density altitude conditions encountered in mountain ranges, to the rain and fog of the littoral environment." Table 4: Aircraft Meteorological Design Limitations* of the SOI lists the maximum HDs of 14,000 ft for takeoff, landing and all in-ground effect manoeuvres. In the same table, the maximum HD for the maximum Gross Weight of 11,900 lbs is 4000 ft. In paragraph 2.3.2.3 these limits are reiterated: "*In order to counter the high density altitude effects that dominate many of the potential theatres of operations for the CH146, it is necessary to examine solutions to improve CH146 performance. The current density altitude limitation for maximum gross weight operations is approximately 4000 ft HD. The current limiting factor is tail rotor authority. Given the increase of CH146 operations in high and hot environments, it is anticipated that future CH146 operations will be conducted at maximum gross weight at 4,000 ft HP and an OAT of 35ºC, which equates to an HD of 7,000 ft.*" In paragraph 2.3.2.3 the SOI offered short- and long-term solutions. The short-term solution was to adapt a "combat configuration" that *"would see the removal of mission kits that are not relevant for the specific operational theatre, as determined by mission analysis, thus optimizing the CH146 available payload to support Land Force Operations."* The SOI offered that *"engineering solutions will be examined to increase the density altitude envelope for all-up weight operations"* as the long-term solution.

1.17.3 In-theatre Turnover

1.17.3.1 The Joint Task Force Afghanistan [JTF(A)] Air Wing comprised all CF air assets deployed in the southwest Asia theatre of operations. On 6 December 2008, the JTF(A) Air Wing stood up and consisted of a headquarters, the Tactical Airlift Unit and the Theatre Support Element for a total of approximately 200 personnel. The initial deployment of the CH146 as part of the CHF(A) and the JTF(A) Air Wing was the sixth personnel rotation (Roto 6).[25] Roto 6 was mainly comprised of RCAF personnel from 408 Tactical Helicopter Squadron (THS). After their six month tour Roto 6 was replaced in May 2009 by Roto 7, manned mainly from 430 Escadron tactique d'hélicoptères (ETAH).

1.17.3.2 During the Roto 6 and Roto 7 in-theatre turnover, Roto 6 personnel presented Roto 7 personnel with a Desert Operations performance presentation that detailed the performance planning required using the AFM charts in use at the time. This presentation made reference to the various WAT, Hover Ceiling IGE/OGE, Cruise Performance and Hover Torque Required IGE/OGE charts. Roto 6 had also created a performance matrix chart entitled Desert Performance Chart that could be used as a quick reference guide for pre-flight performance planning. This chart depicted several IGE/OGE takeoff weights and torque

[25] Roto is used to define the personnel or time period of a specific deployment.

values for various HP and OAT ranges (from 2000' to 6000' HP in 500' increments and 20ºC to 50ºC in 5ºC increments) (Annex H). This unofficial chart was neither validated nor approved by the OAA or the TAA; however, it provided Roto 6 crews with an aircraft performance planning guide that enabled a rough prediction regarding mission acceptability for various atmospheric and aircraft parameters present in theatre. The promulgation of non-airworthiness approved performance charts is unacceptable and not authorized. Condoning of such unofficial matrices encourages the production of other types of uncertified and potentially dangerous "cheat-sheets" by operational aircrew and can significantly elevate the level of risk when conducting flight operations.

1.17.4 Mission Acceptance and Launch Authorization (MALA)

1.17.4.1 The Air Wing had implemented a risk management tool to review the scheduling of missions and to designate the appropriate authority needed to approve the actual launch of the aircraft. This tool, included in the Wing Orders, was called the Mission Acceptance and Launch Authority (MA-LA) process which was a two-part authorization process to manage risk, satisfy operational requirements and assist in decision making. The process asked detailed questions to highlight potential areas of risk. Mission Acceptance and Launch Authority were two different processes. The first part of the MA process was the mission assessment conducted by the CHF(A) staff to consider various criteria such as the type of mission, mission profile, landing zones, threats, etc.; it was usually undertaken 24 hrs in advance for routine operations and 48 - 86 hrs in advance for large scale operations. In the second step of this process the results of the mission assessment were approved, rejected or referred to a higher authority by the applicable mission acceptance authority which was either the CO CHF(A), the Air Wing Commander (WComd) or the Comd JTF (A). The LA process was the second part of the MA-LA process. This was a flying supervisory function used to authorize flights after reviewing conditions that could affect the specific mission such as crew rest, qualifications, time in theatre, weather, and other risk factors at the time of launch. These results were forwarded to the proper launch authority, the CO CHF(A) or the Air WComd. At the time of the accident, the MA-LA matrix had been applied in accordance with the procedures in place for operations in Afghanistan. However further review indicated that when considering landing zones the MA process only differentiated between landing in MOBs, FOBs or at unprepared surfaces; there was no specific criteria for examining the actual conditions of the landing site which could have included size, obstacles, dust suppression, crash-fire-rescue capabilities or the potential of DVE. Within the LA process weather was included as criteria but only examined day or night operations, cloud ceilings and visibility. It did not include specific environmental conditions such as density altitude or elevated OAT.

1.18 Additional Information

1.18.1 Operating Conditions in Afghanistan

1.18.1.1 With a mix of desert regions and rugged mountainous terrain with altitudes up to 24,500 ft and temperatures from -25°C to +53°C, the Afghan theatre provided extremely challenging flying conditions. In particular, the often high HD, which resulted from decreased air density at altitude that was combined with high ambient temperature, negatively affected aircraft performance. These conditions placed the CH146 near or at several of the aircraft’s maximum operating limits, such as the combining gearbox oil temperature, Qm, ITT, battery temperature (primarily on engine start) and the maximum operating OAT. The maximum OAT for the CH146 is +51.7ºC but it is reduced by 2 degrees per 1000 ft of elevation. For operations at Kandahar, Afghanistan the calculated maximum OAT was +45 ºC.

1.18.2 Degraded Visual Environment (DVE)

1.18.2.1 Afghan soil consists mainly of sand and rock. The sand is extremely fine and light and is often compared to talcum powder. In dry conditions helicopters generate a donut-shaped dust cloud, commonly referred to as a dustball, during initial lift-off and the approach/landing that contributes to the DVE known as brown-out. In the most severe dustball/brown-out conditions the entire aircraft becomes engulfed in the dust cloud and, in Afghanistan, these can reach a height of a few hundred ft (Annex A: Photo 7). Helicopter operations in such a DVE are very challenging, reducing visibility for the crew sometimes to the point where the crew loses all visual ground references (Annex A: Photo 8). These dustball/brown-out conditions have been recognized and continue to be a significant risk and threat to operations by many civil and military helicopter operators.

1.18.2.2 In order to maintain position during hovering flight, helicopter pilots select near and far points, both in front and to the side of the aircraft as normal hover references. A dustball will preclude aircrew from using the far points as ground references, limiting them to only the near references which can be just a few feet from the aircraft. Aircrew will also use relative motion in comparison with their selected normal hover references as an indication of aircraft movement or drift. This technique is used to assess drift in both the vertical and horizontal planes, however, vertical movement is more difficult to assess because it relies mainly on depth perception. When encountering a DVE, the motion of the particles within the obscuring phenomena can severely hamper depth perception and also create visual illusions for the crew, like inducing a false sense of relative motion. These illusions can be seen and interpreted in two distinct ways: the aircraft appears to be drifting when in fact it is stationary or the aircraft appears stationary when in fact it is drifting. The most severe dustballs can also obscure all ground references.

1.18.2.3 As previously mentioned, the CH146 does not have see-through technology systems or systems using landing symbology or sensory displays for safe flight in a DVE below V_{MINI}. Additionally, neither of the CH146 systems, handling qualities or flight instruments are designed, certified, approved, intended, nor precise enough to allow aircrew to allow safe flight in a DVE below V_{MINI}. Therefore, aircrew must have the ability to maintain or regain visual ground references quickly or apply a flying procedure that will ensure an effective visual or instrument transition to a point where references can be acquired and maintained allowing for safe flight. Aircrew must rely on cockpit flight instruments or other systems such as a Helmet Mounted Display (HMD) to detect changes in motion/position.

1.18.3 Helmet Mounted Display (HMD)

1.18.3.1 The pilot's helmet can be fitted with a day or a night HMD. The two HMDs are often referred to as the Head-Up-Display[26] (HUD) and are called the Day-HUD and the Night Vision Goggle HUD (NVG-HUD). The two HUDs are different in design, the Day-HUD can only be mounted over the right eye while the NVG-HUD can be mounted over either eye. Both systems display the same symbology and include a drift vector. The Day-HUD hover page displays a drift vector which provides the pilot with drift information. The drift vector is depicted as a simple line with the length representing the rate of drift and the orientation representing the direction of drift (Annex I). This information is only relative to the aircraft movement, only indicates the direction and rate of movement and is not locked on a specific point over the ground like a GPS point, for example. Once drift has occurred and been stopped, there is no way for aircrew to accurately fly back to the point of origin. Unit Flying Orders mandated that the HUD, day or night, be worn at all times in theatre.

1.18.4 Standard Manoeuvre Manual Procedures

1.18.4.1 The SMM details the techniques and procedures used to fly the CH146. The version of the SMM valid at the time of the accident was Ch 3 dated 15 May 2009.

1.18.4.2 Crew Duties - The crew duties specific to each crew position are described in the SMM Table 1-1 - Standard Crew Duties. In Table 1-1, both the FP and the NFP are assigned the duty to "*crosscheck systems and instruments*." The table includes a note that specifies that the FP should resist the temptation to perform NFP duties. The table assigns the NFP the duty of advising the FP of the power setting. Specifically, it states that the NFP must advise the FP when the power setting is at 80% Qm and above in increments of 5%, and approaching 100%. It should be noted that CH146 aircrew have historically operated predominately in colder or temperate climates where they were accustomed to being Qm limited before reaching an engine limitation, such as ITT or N1. The SMM did not indicate how the NFP was to advise the crew about power settings when the Qm was not the power limiting factor.

[26] Head-Up-Display or Heads-Up-Display

1.18.4.3 In addition to the standard crew duties mentioned above, each flying task described in the SMM has a section for crew management which specifies additional crew duties specific to the task described. Table 1-1 stipulated that the FE was responsible at times for conning the aircraft and providing advisory calls to the FP on drift motion by providing verbal drift information derived from his visual ground references. For the task VMC Approach and Landing, the crew management information specifically directs that the FP and the FE shall inform the crew when they lose visual ground references. This direction was not provided for the task VMC Takeoff/Level Off.

1.18.4.4 CH146 Takeoff Procedures - There are two types of takeoff procedures: the no-hover takeoff and the vertical takeoff. The vertical takeoff is further subdivided into the four ft hover takeoff, the MPTO, and the ITO.

1.18.4.5 In accordance with SMM Ch 3, both the MPTO and ITO procedures required a minimum power margin of 20% Qm over and above the required IGE hover torque. There was no minimum power margin specified for a four ft hover vertical takeoff and transition into forward flight using ground effect. There was also a note following the description of the MPTO and prior to the ITO description that stated “*Any hesitation in power application will cause a loss in climb momentum and will require additional power to re-establish the initial rate of climb.*”

1.18.4.6 The SMM Ch 3 stated that the ITO is a composite visual/instrument procedure used to depart an area where obscuring phenomena are expected. Desert operations procedures were published in the SMM during Ch 3 in preparation for the operations in Afghanistan and clearly stated “*The ITO procedure shall be used. Pilots should not attempt the max performance take off procedure when a vertical rejection of the take off is likely. Taking off in brown out conditions should only be attempted when the aircraft weight is within the limit specified by the HOGE chart and appropriate wind azimuth chart.*” Due to the dust conditions in Afghanistan, a rejection of a takeoff is often likely. The reason for mandating an ITO under these conditions is to maximize crew efficiency at flying the aircraft accurately with reference to flight instruments. On takeoff, the FP controls the aircraft using flight instruments until suitable visual references can be acquired and maintained. The NFP can continue cross-checking visual ground references until they are lost and, at the same time, monitor the FP’s performance and instrument indications. In the case of an MPTO, both pilots look outside at visual ground references. If visual ground references are lost partway through the takeoff, the FP has no choice but to transition to flying on instruments. The transition from flying on visual references to flying on instruments takes a few seconds because the FP has to assimilate and process flight instrument information. Once assimilated, the information is used to build an air picture of the aircraft’s attitude and motion. This transition from flying using visual ground references to flying on instruments is recognized as a critical period, thus the stipulation that the FP be on instruments throughout the entire ITO procedure. The direction in the SMM Ch 3 Desert Operations to confirm that the aircraft weight is within the limits of the HOGE and wind azimuth charts is based on the anticipated increased OGE power requirements of the ITO during the takeoff. This is consistent with the intent of having 20% Qm over and above the required IGE hover torque for the MPTO and ITO. Although not exact, it was assessed that the 20% provided a margin of safety for performance during these manoeuvres.

1.18.4.7 Additionally, the SMM Ch 3 stated that the NFP should stand by the controls, as required. The CVR and testimony indicated that the NFP was standing by the controls for the takeoff.

1.18.5 Spatial Disorientation

1.18.5.1 Spatial disorientation is defined in the CF Manual of Instrument Flying, Annex B - SPATIAL DISORIENTATION as “the failure to achieve accurate orientation with respect to the earth’s surface. The attitude of an aircraft is generally determined by reference to the natural horizon or other visual references to the earth’s surface. …If neither horizon nor surface references exist, the aircraft attitude must be determined by artificial means from flight instruments.” Spatial disorientation is generally classified as either unrecognized (Type I), recognized (Type II), or incapacitating (Type III).[27] Defence Research and Development Canada (DRDC) human factors specialists also define spatial disorientation as the failure to sense or sense incorrectly the position, motion and attitude (orientation) of the aircraft with respect to the earth’s surface and the gravitational vertical. The fixed frame of reference that is used for spatial orientation is both the earth’s surface and the gravitation vertical.

1.18.5.2 Situation Awareness (SA) is defined as keeping track of prioritized events and conditions in one’s environment. It is a mental process that a pilot uses to guide his movements, to anticipate events and to build a mental picture of reality. His ability to accomplish this accurately is based on his experience, knowledge, and proficiency as well as how rapidly he can analyze and prioritize changing events correctly during the mission.[28] Operationally, SA in the aviation environment is used to refer to the awareness of the large group of factors that are important to keep the aircraft safe from hazardous situations or potentially dangerous flight paths (including tactical SA and spatial orientation (SO)). The hierarchical structure dictates that SO is part of SA. Analysis of spatial orientation accidents demonstrates that common attention anomalies such as channelized attention, distraction or task saturation[29] could contribute to spatial

[27] A-OA-148-001/AG-000, Manual of Instrument Flying Annex B - SPATIAL DISORIENTATION.
[28] Ibid.
[29] Channelized attention is the focusing of conscious attention on a limited number of environmental cues to the exclusion of others of higher or more immediate priority. Distraction is the interruption of conscious attention to a task by non-task related cues. Task saturation occurs when an individual has too much to attend to at one time; thus missing possibly important cues.

disorientation and loss of SA.[30] Distraction is further defined in The Concise Oxford English Dictionary as "a thing that diverts someone's attention, a thing offering recreation or entertainment, an agitated mental state."

1.18.5.3 For the purposes of this investigation, the term loss of SA refers to the channelized attention, distraction and task saturation suffered by the FP when referring to and crosschecking the ITT gauge during the takeoff procedure. It is not intended to indicate that the FP was engaged or focussed on non-task related activities, events or factors from the takeoff procedure.

1.19 Useful or Effective Investigation Techniques

1.19.1 Mast Torque (Qm) calculations

1.19.1.1 Early in the investigation process, as the CH146 CVFDR or HUMS did not capture Qm, NRC and AETE each developed mathematical methods or used rules of thumb to estimate Qm from the combined engine torques. Both methods were very similar and provided a calculated Qm of approximately 91% Qm (results were within 1% of each other). NRC results are presented in graphical format at Annex F, Graph 4. As a result of additional testing conducted under the auspices of AETE project 2011-023, the AETE final report found that Mast power ratio varies not only with power, but also with HD. Engine to Mast Torque Ratio (QR) was also calculated from the hover performance data and was included in the same report. The QR function found from flight test converts engine power to mast torque as a function of total engine power, HD and OAT. The accident aircraft performance calculations were recalculated using these factors and are presented in Section 2. (See also Annex F, Graph 5).

1.19.2 Performance Calculator Software

1.19.2.1 Measuring actual power available on a production aircraft in real-time is not feasible. Following the accident the Directorate of Aerospace Equipment Program Management (Transport & Helicopter) [DAEPM (TH)] developed software that estimated aircraft power available under given environmental conditions to assist aircrew with aircraft performance planning. The software provided an estimate only and calculations were based on Power Assurance Check (PAC)[31] data for each aircraft and specific ambient environmental conditions.

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[30] Cheung, B. (2004) Spatial Orientation – Nonvisual Spatial Orientation Mechanisms. In: F. Previc, W. Ercoline (Eds.) Spatial Disorientation in Aviation. Progress in Astronautics and Aeronautics Volume 203. pp 37-94. American Institute of Aeronautics and Astronautics, Inc. Restoin, Virginia.

[31] Power Assurance Check – see Annex B.

2 ANALYSIS

General

This was an elaborate and lengthy investigation that focussed mainly on environmental operating conditions, takeoff procedures and CH146 performance. Organizational issues within the RCAF and the CH146 community also surfaced. Three DFS investigators conducted numerous independent interviews with multiple agencies and personnel, including civilian and military representatives from the OEM, NRC, AETE, and QETE; the CH146 WSM; the chain of command; as well as qualified CH146 aircrew at the tactical level and formerly qualified CH146 aircrew at the operational and strategic levels.

The post-crash fire consumed the majority of the aircraft and left little usable material evidence. Both pilots survived the accident and had a good recollection of the events as they unfolded. The CVR/FDR data and historical HUMS data were used in comparison with CH146 baseline performance and other deployed aircraft. These data indicated that the accident aircraft was performing according to the OEM’s specifications for the ambient conditions at the time of the accident. The analysis examined the environmental operating conditions in Afghanistan, the use of the CH146 Day-HUD, Human Factors affecting aircrew performance, the post-crash fire and cabin survivability. The investigation team also reviewed the accident takeoff procedure, CH146 performance charts, ITT exceedences and conducted post-accident performance calculations. Finally, some organizational issues with the CH146 Deployment to Afghanistan were also examined.

2.1 Environmental Operating Conditions in Afghanistan

2.1.1 The crew prepared for the afternoon flight using information gained during the morning mission. During that mission the helicopters landed in the FOB in the designated landing site. The ensuing takeoff from the FOB was less challenging from a performance perspective; after dropping off passengers, which reduced weight, and with a lower OAT, aircraft performance permitted a successful takeoff from the FOB. (However, the investigation revealed that similar DVE conditions existed, and it is confirmed, as described in paragraph 2.7.11, that the #2 aircraft exceeded ITT limits during that morning takeoff as well.) The conditions during the afternoon’s mission were quite different. The landing was not conducted at the designated landing site due to the wind shift and takeoff distance considerations. The OAT was 4ºC higher, creating a higher HD, and the aircraft AUW was heavier, after refuelling at KAF and boarding two passengers. These differences meant that the crew faced a different situation for the accident takeoff; as the combination of these factors would have reduced aircraft performance, this should have warranted more detailed pre-flight performance calculations.

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2.1.2 Dust and Fire Suppression

2.1.2.1 The investigation found that there were no standards for dust suppression or fire suppression methodologies in the Afghanistan theatre of operations. While the larger bases in Afghanistan had hard-surfaced operating areas or other systems in place such as spray-applied solutions, fabric or rigid mats or gravel and grid systems, few of these solutions were available to control dust at remote helicopter landing sites or in FOBs. Fire suppression was also not standardized. While the larger bases could provide Crash Fire Rescue services with adequate fire extinguishing agent or fire suppression systems, implementing similar solutions at remote locations and in FOBs in such a hostile military environment was impractical. Interviews with International Security Assistance Force (ISAF) Flight Safety personnel in KAF revealed that the establishment of theatre-wide standards were seen as impossible to implement at the time. The various reasons included the number of FOBs, cost, resource availability, the number of disparate countries responsible for maintaining FOBs and logistical issues. The accident FOB was considered austere, not Canadian-controlled and, did not employ any dust or fire suppression measures. While the FOB had handheld fire extinguishers, these were not effective facing this size of post-crash fire.

2.1.2.2 Attempts to control dust were often beyond Canadian control or influence, and operations in dustballs were recognized as an inherent risk of operating in the Afghan theatre. Some nations implemented mitigating measures for dust landings and takeoffs in FOBs or unprepared landing zones such as the identification and assessment of various criteria to determine the suitability, selection or rejection of a FOB or unprepared landing zones for helicopter operations. If certain dust or fire suppression criteria were not met, then operations would not take place. For CF operations, a review of CHF(A) documents indicated that training and flying orders were in place for dust landing procedures, however, these did not contain criteria to determine the suitability, selection or rejection of a FOB or unprepared landing zones considering dustballs or potential helicopter operations in DVE. Standard Operating Procedures (SOPs) for deployed operations should include accurate descriptions and evaluations of FOBs and landing zones for flight planning purposes and these should be updated regularly. (Of note, measures were taken in subsequent Rotos to ensure FOBs were sprayed with water for operations to occur.)

2.1.3 Degraded Visual Environment

2.1.3.1 In deciding to land at an alternate location inside the FOB, the crew’s reasoning was sound in that this allowed for a landing into wind and also provided maximum distance available for the takeoff and departure. Landing into wind maximizes aircraft performance and keeps the dustball behind the aircraft longer, thereby allowing the crew to maintain visual ground references for a

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longer time. The distance available for the takeoff was important due to obstacles in and around the FOB.

2.1.3.2 Assessing dust conditions in a landing zone prior to landing is very difficult. Both crews were unable to accurately assess the dust conditions in the FOB prior to the landing. The accident crew reported that the dustball created during the accident takeoff was one of the worst that they had ever experienced. In their opinion, the obscuring phenomena played a major role in this accident in that it severely impeded the FP’s and FE’s ability to detect drift and ultimately the FP’s ability to correct the unintended drift, to see and to avoid the barrier. Photos and videos of multiple landings and takeoffs into the FOB by both CF and coalition helicopters taken the day of the accident revealed the creation of intense dustballs on all occasions. Deciding to land at the designated site or an alternate site within the FOB would not have eliminated or reduced the creation or intensity of the dustball. With the sand conditions present and lack of dust suppression, the creation of an intense dustball contributed to a DVE for the accident crew.

2.1.3.3 Both the FE and the FP, who were seated on the right side in the helicopter, lost visual ground references while the NFP, who was seated on the left side, maintained his references. In a dustball, the density of the obscuring phenomena is greater near the main rotor blade tips, (in the donut-shaped outer area of reduced visibility created by the rotor downwash) than it is in the centre. Once in the hover, as the aircraft drifted to the right, it moved towards the outer area of reduced visibility. This explains why both the FP and FE lost visual ground references while the NFP, who was able to see references towards the centre of the dustball, did not.

2.1.3.4 Contributing to the loss of the FE’s references was the type of ALSE equipment used. As the cargo doors were removed, which was the standard configuration for operations in Afghanistan, the FE was fully exposed to the effects of the dust, more so than the pilots in the front cabin. However, even had the doors been installed and closed, the intensity of the DVE was such that visibility through the cargo door window or through goggles would likely have been equally poor. In this dustball, the FE’s ability to see his visual references and, therefore, communicate information concerning drift and obstacles would have been significantly degraded.

2.1.3.5 As previously explained, within the MA-LA process there was no specific criteria for dust suppression, crash-fire-rescue capabilities or the potential of DVE or environmental conditions such as density altitude or elevated OAT. At the time the MA-LA process was seen as a rigorous tool supporting mission planning, risk identification and mitigation and final launch authorization. The investigation found that the MA-LA process did not support or lead to a proper assessment of the climatic conditions, and hence aircraft performance for that specific mission at the FOB that day.

2.1.4 To summarize, due to different OAT, HD and AUW, the crew was faced with degraded aircraft performance when compared to the morning takeoff. While the selection of an alternate landing site did not play a role in the creation or intensity of the dustball, the lack of dust suppression methodologies and the poor sand conditions did. Additionally, the FP lost all visual hover references while the FE’s ability to provide the FP with drift information was significantly degraded. Together, these factors combined to create a DVE that completely removed the crew’s visual references, which was a main contributor and causal factor in this accident.

2.2 CH146 Day-HUD

2.2.1 Roto 7 deployed with the intent to use both the Day-HUD and NVG-HUD at all times. At night, both the NVGs and the NVG-HUD performed well. The main reason for operating with the Day-HUD was to allow for continuity between day and night flying. However, some limitations of the Day-HUD did not surface until actual operations and use of the Day-HUD in Afghanistan forced a reconsideration of this approach. Aircrew reported various problems or inconsistencies such as a pink tint, a blind spot, and difficulties reading the Day-HUD during certain daytime illumination conditions. Furthermore, due to the weight and location of the HUD on the helmet, some aircrew experienced neck pain which led to fatigue. Apart from the issues of neck pain, the issues with the Day-HUD were not present with the NVG-HUD. Some aircrew were concerned that the pink tint and blind spot would hinder the field of view and limit their ability to detect enemy presence and/or actions while flying certain missions. Additionally, it was discovered that under certain conditions, the intensity of the illumination from the sun reflecting on the sand was such that aircrew could not read the Day-HUD even with the symbology display at full intensity. These issues were known within the CHF(A) chain of command and with these limitations, continued reliance on and use of the Day-HUD during certain flying conditions was seen as a higher risk than not using it at all.

2.2.2 To mitigate this risk, following the identification of these issues, the CO ensured that aircrew were aware of the limitations, directed that aircrew use the cockpit instruments as a primary reference if the Day-HUD did not perform to expectations and left individual aircrew to decide, depending on the flight conditions, whether or not to wear the Day-HUD. The CO’s intent and risk mitigation, provided via verbal orders, was clear and reasonable; the modification of his unit’s flying orders was seen as an administrative issue that would follow in time and so at the time of accident, Unit Flying Orders had not been updated. The reason why the Unit Flying Orders did not reflect the CO’s most recent direction on the use of the Day HUD when the accident occurred was because the unit leadership faced a barrage of issues in May and June, almost all of them related to increasing temperature and the associated limitations experienced on the Griffon, aircraft OAT limitations, never exceed speed (VNE) limitations, ITT and Ng limitations, to name a few.[32] In the span of three weeks, CHF(A) went from a situation where they could fly as per the SMM to one where a number of manoeuvres could no longer be flown as per the SMM. The implications were quite significant. The CO directed his Operations Officer; he was double hatted as the Unit Standards Officer and tasked to communicate these challenges to 1 Wing and 1 Cdn Air Div since they needed to transition rapidly from flying off the Qm to flying off the ITT and Ng limitations. This was a comprehensive task and saturated the Operations cell for the better part of two months (mid-May to mid-July). Having lost some capacity in the Operations Centre, the CO elected to use alternate methods (verbal orders, Aircrew Information Files) to communicate his intent and directions, during that period. The amendments to the use of the Day-HUD were communicated through verbal orders and this verbal direction allowed aircrew to decide on the use of the Day-HUD and accept the operational risk at their level. As such, the decision to not wear the Day-HUD was common practice with aircrew for certain missions under certain flight conditions.

2.2.3 While the use of the Day-HUD could be seen as a significant brownout risk mitigation tool, it should be emphasized that the CH146 HUD and its internal symbology is not certified as a primary flight instrument. As noted in the AETE Project Directive 2000-004, CH146 NVG HUD, Draft Report, undated (project closure by AFTEC / A/A3 APT, 12 Aug 2011), *“The use of the AN/AVS-503 ANVIS HUD during the performance of hovering and low speed flight manoeuvring [at night under NVG] modestly increased aircrew situational awareness and was satisfactory. The flying pilot should minimize the use of the AN/AVS-503 ANVIS HUD and continue to rely on external visual cues during hovering and low speed flight operations. The Hover and Transition vectors should be used only as a secondary cue by the flying pilot during hovering and low speed flight manoeuvring in degraded visual cueing environments.”* The AETE Project Directive 2005-012, CH146 Day Helmet Mounted Display, Final Report, 29 Jan 2007, includes a CAUTION statement indicating: *“The use of the HUD attitude reference line may assist in maintaining SA, but when conditions dictate inadvertent instrument meteorological conditions (IIMC) procedures, the aircraft's primary flight instruments must be referenced.”* The CAUTION statement above is reiterated in the SMM under the Task 114 Perform IIMC

[32] It is important to understand that, at the time, CHF(A) were also trying to assess the second and third order effects that higher than normal temperatures would have on operations. This example speaks of a real time situation that occurred in June where the SAMEO and one of the CH146 test pilots requested guidance after maintenance was completed on a helicopter. The maintenance procedure required a test flight to be completed (after the maintenance action) so that autorotation parameters could be confirmed within limits. Upon reviewing the autorotation charts, the test pilot realized that the rotor speed to be achieved for the altitude and temperature at Kandahar was outside the allowed aircraft limits. Technically, they could therefore not confirm the aircraft serviceable for flight after routine maintenance. Following consultation with the WSM and the OEM, clear direction regarding the applicable aircraft limits (to declare the aircraft serviceable) was provided. For a period of two months, as they entered the warmer months of the year in Afghanistan, they continued to try and identify those second and third order effects that were not necessarily obvious but that could have arisen to impact to CH146 maintenance and operations in Afghanistan.

Procedures, Night Considerations, paragraph 7. A NOTE is also included which indicates: *The information displayed on the HUD is NOT certified for use in instrument flight conditions.* However a contradictory statement is provided under Task 106, Perform VMC Approach/Landing, Desert Operations, paragraph 37, where it is stated: *Once references are lost, the landing can be accomplished by flying on HUD/HMD using a scan between the ATT-G/S-ATT-Rad Alt symbology.*

2.2.4 During the accident flight the crew did not use the Day-HUD. Approximately five seconds after lift off right drift was identified by the NFP and verbalized to the crew. The FP acknowledged the first drifting right call and thus was aware of the aircraft drift. Three seconds later, the NFP again called drifting right two seconds prior to barrier impact. It is impossible to determine if the use of the Day-HUD would have assisted the FP in eliminating the right drift or if it could have prevented the accident, but it certainly could not have assisted in returning the aircraft to the original takeoff position. While a drift indicator is seen as a desirable brownout risk mitigation instrument, as previously explained, AETE determined that pilots should minimize the use of the Day-HUD, rely on external visual cues and only use the drift vector as a secondary cue during hovering and low speed flight manoeuvring in DVE.

2.2.5 Aircraft groundspeed was estimated using the accident timeline and the distance from the takeoff point to the barrier. Due to the unknown position of the helicopter after takeoff and unknown start time of the right drift, calculations varied depending on the time estimated to travel the 95 ft from the takeoff spot to the impact point. Without an accurate time start, physical start point and aircraft acceleration, these calculations could not be used conclusively. However it is possible that the aircraft could have accelerated to greater than 10 kts groundspeed which would have eliminated the drift vector. The investigation concluded that the Day-HUD drift vector would have only provided the FP with an additional source of drift information, re-confirming the direction and rate of drift to the FP. It is unknown if the use of the Day-HUD would have assisted the FP to recognize, reduce or eliminate the drift more quickly.

2.3 Human Factors

2.3.1 Loss of Situation Awareness

2.3.1.1 The total flight duration from skids clear of the ground to impact with the barrier was under 10 seconds. Crew testimony and CVR analysis indicated that that time was very busy for the crew. The FP commenced the takeoff looking at his normal hover references but upon hearing the NFP’s call of 95% Qm, coupled with his concern for the ITT limit, the FP quickly cross-checked the ITT gauge inside the cockpit.[33] At that specific moment the NFP realized the

[33] The value of 95% Qm was reached due to the combination of the ITT exceedence, the time spent in ground effect and the droop in the main rotor RPM.

aircraft was drifting to right at an approximate walking pace and called “drifting right,” as per the SMM. The FP’s attention was drawn back outside in an attempt to control the drift using visual ground references but they were no longer available. With no visual ground references, the FP transitioned to the ITO, relying on flight instruments as per the briefed takeoff plan. The CH146 has no single aircraft instrument that can provide drift information and assist the pilot in maintaining control of the A/C in the hover. In addition, the rapid and numerous transitions of attention and focus from scanning visual references outside the cockpit to monitoring the flight and engine instruments inside the cockpit did not allow sufficient time for the FP to detect, interpret, and understand the flight information; build an appropriate air picture; and then respond with proper flight control inputs. FDR data at Annex F confirms that the FP did not immediately action the information received. However, DRDC Human Factors specialists have determined that the normal delay or reaction time required from detection until proper flight control input could be as long as five seconds.[34] While there was a delay in reaction time, which is normal or routine behaviour, it is assessed that the NFP calls may not have improved the FP’s SA.

2.3.1.2 Without an appropriate air picture the FP could not know which control inputs were necessary to control the aircraft in the desired manner. With the FP unable to effectively stop the drift and/or gain altitude, the helicopter continued to drift towards the unseen barrier within the dustball. This analysis led the investigation to conclude that due to the rapid and numerous transitions of shifting focus, the FP was distracted and task-saturated which led to a loss of SA during the takeoff sequence.

2.3.2 Crew Training, Coordination and Communication

2.3.2.1 As indicated in section 1.5, a review of the RCAF helicopter dustball/snowball training, exposure to DVE and aircrew training files revealed a discrepancy in and lack of initial and advance training for operations in obscuring phenomena for the FP. Notwithstanding the apparent training shortfall, discussions with some CHF(A) aircrew indicated that the FP’s time in theatre (over two months) afforded the opportunity to be familiar with dustball operations. The investigation determined that the training provided to the FP for operations in dustball/snowball and DVE was insufficient for dealing with the DVE encountered during the accident flight. Upon further review, the investigation determined that the training for operations in obscuring phenomena provided to CF helicopter

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[34] DRDC human factors specialists have determined that the process of identifying an object can take 1.05 seconds. If a decision must be made on what to do, this can take an additional 2.00 seconds. Reaction time can also be affected by the time interval required to shift vision from outside the aircraft to inside the aircraft which, can increase response times by an additional 2.39 seconds due to the physiological time that is spent with eye movements to an instrument panel, recognize the instrument reading, then move back to outside the cockpit and perceive the outside environment. Studies have shown that there is also an inherent delay (seconds) in regaining orientation information when transition from VMC to IMC (especially from head out to head down). This latency would be lengthened if the pilot was disoriented even when it is recognized SD.

pilots, and CH146 aircrew in particular, should be improved. The use of advanced simulators and training exercises in actual conditions could provide potential mitigating training solutions.

2.3.2.2 Crew actions and coordination was analysed via a detailed review of the CVR recording and crew testimony. This revealed that although they were extremely busy, the crew had been working well as a team and that communication among the crew was generally effective and in accordance with the SMM. Two factors surfaced that could have altered the outcome of the flight: overlapping communications and informing the rest of the crew that visual ground references were lost.

2.3.2.3 CVR analysis revealed that there were several internal calls made by the crew and in some instances these communications overlapped. Aircraft radio limitations in transmit and receive functions do not allow for continuous transmissions to be sent and heard by all stations at the same time. In this case, drifting calls made by the FE were not heard by the FP. The investigation concluded that the FP was aware of the drifting condition and even if these calls had been heard they would only have reconfirmed what he already knew.

2.3.2.4 CVR analysis and interviews also revealed that the FP did not inform the crew that he had lost visual ground references or that he was flying on instruments. Had either call been made, the NFP could have taken control of the aircraft since he still had visual ground references. However, it cannot be determined with any degree of confidence that had the NFP taken control, the right drift would have been corrected in sufficient time to avoid colliding with the barrier or that the NFP would not have also eventually lost visual references.

2.3.3 In the most critical case where the entire crew loses visual references, the appropriate actions would be to advise the rest of the crew, stabilize the aircraft as much as possible using flight instruments and establish a climb profile through the obscuring phenomena. While the FE had time to advise the crew that he had lost visual references, the investigation concluded that the FP was distracted and task saturated during the takeoff due to the numerous changes in his focus during the 10 seconds prior to impact during his attempt to stabilize the aircraft and climb away. This can explain why the FP never informed the crew that he had lost visual ground references or that he was flying on instruments.

2.4 Post-Crash Fire

2.4.1 Before exiting the aircraft, the FP pulled both Fire Handles, which is the second of four steps in the Engine Fire checklist response. The first step, closing the throttles, and the third step, activating the fire extinguisher switch to main and then reserve, were not actioned. The investigation could not conclude if the engine fire bottles were discharged. In any event, these steps are for the engine compartment and would not have aided in extinguishing the post-accident

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cabin fire. The fourth step, Emergency Ground Egress was also only partially completed.

2.4.2 The first and second steps of the Emergency Ground Egress procedure were not carried out, leaving the throttles open and the Battery Bus switches ON. The third step, Rotor Brake, was not required but completed. The steps that were completed are steps that have an associated cueing: visual cueing for both Fire Handles and auditory cueing for the Rotor Brake (engine noise). All omitted steps (bold steps in Annex J) were steps that are required to be committed to memory and do not have specific associated cueing. The pilots had the steps committed to memory but it is likely that the actions were simply omitted in the stress and confusion of the situation.

2.4.3 The post-crash fire started very rapidly in the upper area of the rear cabin and was visible to the survivors before they exited the aircraft. While the ignition source could not be specifically identified, the rapidity at which the fire developed indicates that the fire had a readily available source of fuel. Both hydraulic fluid and fuel supply lines are located in the upper rear cabin area and may have been compromised during impact. When the main rotor blades struck the barrier, the rotational moment forces of the main rotor transferred to the main transmission and caused it to come free from its mounts, thereby possibly severing these lines.

2.5 Cabin Survivability

2.5.1 The initial impact forces were survivable yet only one person was able to successfully egress from the aircraft cabin. The three remaining people were not able to egress due to incapacitation, impact injury, post-crash fire, disorientation, physical restraint, or blocked exits.

2.5.2 The prototype CRH was under OT&E and only a limited number of harness sizes were produced, delivered and available (five medium, 10 large and 15 extra large). The investigation was unable to retrieve official supply documentation pertaining to the sizes and distribution of the prototype CRHs and CRTs, however, an unofficial survey taken in theatre indicated that most FEs and DGs were using a prototype CRH which was too large and did not fit properly. A properly fitted and adjusted CRH and CRT, when connected to a correct attachment point, will provide proper restraint and allow, as indicated in the SMM, no more than one third of a person’s body to project beyond the aircraft door opening. Due to the limited size availability and the loose play that some CRHs allowed, some length combinations of the prototype CRH/CRTs could not be adjusted or shortened to prevent the entire body from being projected beyond the door opening.

2.5.3 The locations in the aircraft where the CRTs can be attached are also a safety concern. A properly fitted and adjusted CRH and CRT may restrict aircrew from effectively performing their duties in the cabin or allow more than one third of the body to project out of the aircraft, depending on which attachment point is used. Post-accident discussions with 1 Wing FEs indicated that there was no 1 Wing or CHF(A) policy or procedure directing which attachment points FEs and DGs should use during various phases of flight. The issue was that with the two M134D Dillon guns mounted in the CH146 the front transmission anchor points were no longer accessible due to the presence of the ammunition cans and therefore the transmission side wall anchor points had to be used instead. Due to the ad hoc distribution, lack of official supply documentation on the prototype CRH/CRTs and fire damage, the investigation could neither determine if the harnesses were fitted and adjusted properly nor which attachment points were used.

2.5.4 The investigation’s DRDC human factors specialist indicated that, in combination with equipment, the Fragmentation Protective Vest (FPV) worn by the FE and the DG provided limited flexion, extension, abduction and rotation at the shoulder, restrictions known by CF Land Forces. These movement restrictions limited the effective reach envelope of the wearer. For FEs and DGs, two other pieces of ALSE strapped over top of the FPV exacerbated the problem. Therefore, to extricate themselves, the FE and DG would likely have had to twist their bodies with extreme difficulty to free themselves from the debris generated by the crash sequence.

2.5.5 The FE was seated on the right transmission side-facing seat in the rear cabin area and when the aircraft came to rest, he would have been facing the ground if still in his seat. In order to egress, the FE would have had to have been physically able to follow a relatively unimpeded path towards the cockpit area before it was consumed by the post-crash fire, which appeared to originate also in the rear cabin area. The Coroner’s medical examination identified that the FE was not fatally injured on impact; however, the investigation could not conclude the reason for the FEs inability to egress the aircraft. It is possible that the FE may have been disoriented or injured following the impact and subsequent crash. No calls for assistance from the FE were heard by other crew members, possibly indicating he may have been somehow rendered unconscious during the crash sequence. Alternatively, there is very little cabin space on the side of the transmission (Annex A: Photo 9) and the combination of ALSE and personal protective equipment with the proximity of the M134D door gun further limited his freedom of movement. Considering the aircraft’s initial impact, subsequent rotation, and final position resting on its right side, the FE may have been injured by the violent rotation and contact with the door gun. The door gun would likely have collapsed towards the inside of the cabin, further impeding his egress. The evidence suggests the FE was precluded from successful egress because he was either unconscious, injured, disoriented, did not have time to undo his restraints or was impeded by the door gun or surrounding aircraft structure.

2.5.6 The DG was seated on the left transmission side-facing seat in the rear cabin area and when the aircraft came to rest, he would have been facing skyward if still in his seat. The Coroner’s examination indicated that the significance of the impact and the DG’s possible contact with the aircraft or his door gun would certainly have incapacitated the DG and may even have rendered him unconscious. The inability to undo his restraints, impeded by the door gun or surrounding aircraft structures and the bulk of the equipment he was wearing, could have also contributed to the DG’s inability to egress. The most likely scenario is that the DG was hit by the handgrip of the M134D door gun during the violent rotational moment when the aircraft first struck the barrier, sufficiently injuring and incapacitating him such that egress was not possible.

2.5.7 The Coalition soldier was seated on the floor on the right side of the cabin, behind the right seat pilot and forward of the FE. While attempting to render assistance to the three people still trapped in the aircraft, the pilots noticed that at least one leg was protruding from underneath the aircraft, approximately where the Coalition soldier was seated. The uniform was identified to be camouflage pattern similar to what the Coalition soldier was wearing. Although the investigation could not determine with certainty his exact seating position at the cabin door, analysis of the injury pattern indicates that the Coalition soldier was facing the right side of the helicopter with both legs hanging outside at the time of impact. His legs became pinned underneath the helicopter as it rolled onto its right side, precluding him from exiting the aircraft before the post-crash fire reached that area. The multiple injuries specified in the Coroner’s report are consistent with the Coalition soldier being violently thrown towards the ground, likely due to the violent rotational moment of the aircraft. The investigation could neither conclude what would have been the Coalition soldier’s final resting place had he been seated in an approved seat wearing an approved lap belt - though it is possible that it could have prevented him from being pinned underneath the aircraft - nor what impact it could have had on his egress.

2.6 Accident Takeoff Procedure

2.6.1 Based on their perception of aircraft performance and the anticipated degraded visual conditions from their self-generated dustball, the accident crew developed a takeoff plan while emplaning the two passengers. As they circled overhead, the accident crew watched the #2 aircraft takeoff and narrowly clear the barrier. Although difficult to measure accurately due to their elevated position and distance they estimated that the #2 aircraft had cleared the barrier by only 10 ft (The investigation found that the #2 aircraft did not clear the barrier by the 15 ft requirement stipulated in the SMM). Based on this and the radio transmission from #2, they were aware that their own takeoff would demand maximum performance. However, neither of these factors cued any member of the crew to reconsider performance calculations or the takeoff attempt. These factors only reinforced their plan to land within the first third of the FOB in order to maximize their takeoff distance available from the barrier. During the pre-takeoff discussion, the FO intended to conduct an ITO but in order to maximize vertical obstacle clearance the AC, who realized that the takeoff would require maximum power, suggested to the FO to use more power than required for an ITO. The

AC knew the takeoff would be challenging and that the aircraft would be at the limit of its performance capabilities. However, even during the takeoff attempt, the intensity of the dustball, the loss of references, drift as well as height and proximity of the barriers weighed in as more critical factors than the expected aircraft performance.

2.6.2 The plan was to combine two separate takeoff techniques: the MPTO to use all available power to clear the barrier while visual references were still available and the ITO once visual references were lost in the DVE. Specifically, the MPTO technique was to be used to generate the maximum vertical separation from the ground and surrounding obstacles and to clear the barrier by at least 15 ft as specified in the SMM. Once all visual references disappeared, the ITO procedure was to provide both forward and vertical speed to eventually exit forward of the dustball. This combination of the two takeoff procedures is contrary to the takeoff procedure detailed in the DESERT OPS section of Task 106 within the SMM Ch 3. Paragraph 43 indicates that when conducting a takeoff in brownout conditions, “*The ITO procedure shall be used. Pilots should not attempt the max performance take off procedure when a vertical rejection of the take off is likely. Taking off in brown out conditions should only be attempted when the aircraft weight is within the limit specified by the HOGE chart and appropriate wind azimuth chart.”* However, the SMM was not clear in recommending the use of either an ITO or an MPTO when conducting takeoffs in a confined area where the possibility of a DVE exists. In addition, if performed as described (in paragraph 9. a. of Task 105), an MPTO would create problems with dustball generation due to the requirement to first takeoff to a four ft hover and confirm power, descend to one ft and then commence the MPTO. The crew did not attempt this initial power check as it would have initiated the dustball and the subsequent transition to an ITO from an aborted MPTO, once airborne and drifting, would not have been an acceptable solution. Instead they planned to takeoff from the ground and proceed directly with the MPTO and ITO. The investigation found that the intent to conduct the combination of a modified MPTO and transition to an ITO was a logical plan for the crew at the time facing the conditions they faced that day. However, it raises several issues. This was not an approved procedure and this combination of both techniques would have increased pilot workload during the takeoff, which is conducive to an increased likelihood for a loss of SA. Additionally, the crew had to clear the 8 ft barrier by 15 ft and therefore had to be able to hover at 23 feet AGL. Finally, had they performed pre-flight performance planning and calculations, or considered the directions provided in the SMM to consult HOGE and wind azimuth charts, they would have discovered the overweight situation and the flawed plan from its inception; an MPTO takeoff had to consider OGE parameters. The subsequent takeoff revealed problems with the ITO procedure that had not been considered either by the accident crew, those in theatre or others within the CH146 community.

2.6.3 Interviews with both current and former CH146 pilots at the tactical, operational, and strategic levels revealed two major issues. First, the ITO procedure was not developed or intended to be flown from confined areas or without obstacle clearance considerations. The ITO was not designed to be flown from restricted areas, such as FOBs, for the simple reason that manoeuvring for obstacle clearance and avoidance always requires good visual references. Second, the ITO procedure did not account for the aerodynamic phenomenon known as tail rotor couple[35], or in other words right drift induced by the tail rotor. Helicopters normally do not hover in a level attitude. The CH146 hovers slightly nose high to compensate for a forward tilt of the main transmission that improves its forward flight characteristics. Additionally, when in a wings-level hover tail rotor thrust causes the CH146 to drift right. To counter this, flight controls are rigged such that a left cyclic bias is incorporated and, as a result, a slight left wing low attitude is introduced to keep the helicopter stationary. Therefore, when a pilot slightly changes the hover attitude from left wing low and nose-high to wings level and on the horizon, neither tail rotor thrust nor main transmission tilt are compensated for and the helicopter will drift right and forward, respectively.

2.6.4 The helicopter's inherent hover instability is also responsible for drift. The helicopter is only stabilized in the hover by the pilot's active control inputs, and that can only be accomplished with adequate references. Any of a number of variations in localized wind or turbulence around the aircraft will cause the aircraft to drift. The fidelity of a traditional attitude indicator is inadequate to provide the degree of references that the pilot requires to control position, attitude, and movement.

2.6.5 The crew described the ITO technique using the terminology "bar-on-bar." The bar-on-bar technique was explained by the accident and other CHF(A) aircrew as superimposing the attitude indicator's artificial aircraft symbol over the horizon line. The SMM Ch 3 did not utilize or refer to bar-on-bar terminology, however, it did direct aircrew to "*maintain the aircraft in a flat pitch attitude*[36] *on*

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[35] The following definition for tail rotor couple is taken from the A-12-050-001/PT-001, Manual of Aerodynamics*: "Hovering flight requires that a position be maintained over the ground. But, the tail rotor anti-torque force (operating at right angles to the aircraft heading), produces sidewards drift (to the right) proportional to the tail rotor thrust. The drift must be overcome by flapping the main rotor so that a lateral main rotor force balances the tail rotor anti-torque force. As the helicopter point of suspension from the main rotor is above the point where the tail rotor thrust acts, a main-tail rotor couple is set up, which will roll the machine to the left. This rolling couple in turn produces a couple between the main rotor lift force operating through the point of suspension and the aircraft centre-of-gravity. The helicopters will hover, left side low, balanced by the two couples."*

[36] Pitch angle is the angular difference between the chord line of a rotor blade and a reference datum (Manual of Aerodynamics, A-12-050-001/PT-001). With helicopters, flat pitch would refer to a neutral, or zero, pitch angle of the main rotor blades regardless of aircraft attitude and this usually refers to the pitch angle of the rotor blades being flat which is associated with a lower collective position. There is some confusion created when adding the word "attitude". A flat pitch attitude is thought to be referring to the overall attitude of the helicopter and is not a standard term due to the conflict with the definition associated with rotor blade angle. In this case, a flat

the ADI” (attitude director indicator), which is interpreted by aircrew to mean wings level and on the horizon. Therefore, when properly flown by aircrew, a lower than hover attitude pitch and a wings-level roll combine to accelerate the helicopter forward with right drift. The forward acceleration is required in the ITO in order for the helicopter to attain $V_{MINI,}$ however, the right drift is a hazardous and unwanted effect, especially in a confined area where DVE may exist.

2.6.6 During the field investigation, the lead investigator selected a few CHF(A) CH146 aircrew to fly the ITO in visual conditions. Results of three flown ITO procedures revealed that the aircraft drifted forward and to the right on every occasion. The SMM Ch 3 only mentioned a flat pitch attitude for the ITO technique and provided no direction on the desired roll attitude, leaving it up to the aircrew to determine. While the inherent hover instability and the lack of adequate instrumentation and awareness cues in this flight regime (low speed and poor visibility) must be considered, the direction provided in the ITO section of the SMM, and the crew’s bar-on-bar interpretation and application of this technique, also contributed to the forward and right drift of the helicopter. The ITO, as described in the SMM and as interpreted by some aircrew, created intentional forward drift but also unwanted and unintentional right drift.

2.7 CVFDR and HUMS Analysis

2.7.1 A comparison of FDR data from both aircraft was completed and the results are depicted in Annex F. Aircraft orientation and pilot inputs were analyzed by reviewing pilot interviews and CVFDR data. Cyclic movement in the longitudinal (fore and aft) and lateral (left and right) planes as well as roll attitude were examined. Heading data, tail rotor pedal inputs and corresponding heading changes were reviewed. Finally collective position and estimated Qm values were also studied. The FDR data indicated that there were no engine N1 limit exceedences.

2.7.2 The comparison of cyclic position – longitudinal (Annex F: Graph 1) shows some minor variation between the two aircraft but nothing that was deemed out of the norm for an aircraft on a departure flight profile. The comparison of the cyclic position – lateral (Annex F: Graph 2) shows a right cyclic input between the five and 10 second mark for the accident aircraft. This right cyclic input is also reflected in the aircraft roll attitude data (Annex F: Graph 7) which shows a steady increase in right bank angle to a maximum value of approximately 6º right bank. Both the cyclic position – lateral and the roll attitude show that corrective actions were introduced by the FP at the 10 second mark.

2.7.3 The heading data taken from the FDR, Annex F: Graph 6, shows a heading change from 221º to 199º (a 22º left turn). This is initially a slow and gradual heading change that increases considerably between the five and 10

pitch attitude is non-standard and is intended to refer to the helicopter’s attitude, or pitch, in level or hovering flight.

second mark. Changes in heading data reveal that the FP made positive inputs to correct the aircraft heading back to 207º indicating that the FP had at least partial SA on the aircraft situation.

2.7.4 For the vertical climb, two sources of data were analysed: estimated Qm and collective position. While Qm is not very telling, the collective position shows a difference in collective increase between accident aircraft and the #2 aircraft.

2.7.5 The #2 aircraft’s collective position increases gradually and steadily to a maximum position of 70% of travel. The collective position for the accident aircraft shows a staged application of collective. It is increased in stages twice to a maximum position of 72% of travel and then decreased to 69% of travel at the five second mark before settling at approximately 71% of travel for the remainder of the flight.

2.7.6 From the accident timeline derived from both the CVR and witness testimony it was identified that the FP was distracted by cross-checking the ITT gauge as he looked inside the cockpit upon hearing the NFP’s call of 95% Qm. The FP’s attention was then refocused outside to visual references when the drifting right call was first made by the NFP. These head movements from the FP occur near the five second mark, which coincide with the flight control inputs that translated into right bank and left yaw. The five second mark is also the point at which the FP lost visual ground references. Distracted by cross-checking the ITT gauge and now having lost visual ground references, the FP focussed his attention for the final five seconds of the flight back inside the cockpit to control the helicopter and transition to the ITO procedure using flight instruments.

2.7.7 Several factors at play included the inadvertent initial drift and yaw; the possible drift and yaw due to DVE, illusion and motion; the transition to the ITO procedure; and the staged application of collective in the climb. Considering CVFDR review and pilot interviews, it is assessed that the initial drift and yaw deviations on takeoff from the planned departure profile were inadvertent and unwanted. FDR data may indicate the amount of aircraft motion and how much of that was due to pilot inputs and what the inputs were intended to correct. However, in such a dynamic situation considering the helicopter’s inherent instability and with variables affecting the aircraft attitude such as wind and weight combined with visibility, perception and acceleration cues affecting pilots in a DVE, it is difficult to conclude why certain pilot inputs were made in this situation. Without visual references, pilots may be inclined to respond to perceived acceleration cues or “seat of the pants” feel. For example, with the forward position of the cockpit relative to the aircraft centre of gravity or mast, a left yaw could have been perceived as a left roll. Conversely, a right roll could have been perceived as a right yaw, perhaps influencing pilot to input left pedal. This could have contributed to the FP pedal or right cyclic inputs beyond what was required. Only adequate visual references or advanced aircraft auto-hover systems could have prevented the inadvertent and unwanted drift.

2.7.8 As previously explained, the ITO procedure called for a flat pitch, wings level or bar on bar aircraft attitude. The cyclic movement required from a normal hover position to adopt and transition to the ITO forced the pilot to move the cyclic forward (dot on the horizon) and to the right (wings level). This right cyclic input eliminated the aerodynamic forces required to counter tail rotor drift and contributed to the forward and right drift.

2.7.9 For the climb profile, the more consistent the collective increase, the more efficient the main rotor becomes at generating vertical lift. The SMM states with regard to collective increase that, "*Any hesitation in power application will cause a loss in climb momentum and will require additional power to re-establish the initial rate of climb.*" Due to the plan to execute a MTPO before transitioning into an ITO, which requires the crew to operate the aircraft at or near maximum power and to be conscious of the aircraft limits, the FP attempted to conduct the takeoff while trying to respect and stay within these limits. Upon hearing the NFP's call of 95% Qm and then noticing the ITT, the FP reduced collective to 85% Qm which also reduced or eliminated climb momentum. However, given the environmental conditions present at the FOB, the FP would have had to exceed normal aircraft limits (ITT, Qm and/or N1) in order to execute the takeoff and clear the barrier.

2.7.10 Forward acceleration also aids in generating vertical lift as the main rotor accelerates through its downwash or turbulent air and flies into clean air. This aircraft movement is referred as translational lift.[37] The accident aircraft, due to the right drift towards the one to two o'clock position, did not have sufficient time or distance available between the takeoff point and the impact point to go through translational lift. The #2 aircraft, following its intended departure path (refer to Figure 1: FOB diagram), also had little time and distance available to fly through translational lift before having to cross the barrier. However, as #2 crossed the barrier sooner, this meant much less time spent in the dustball.

2.7.11 The #2 crew attempted and completed the same takeoff as the accident crew, combining an ITO takeoff with an MPTO with no hesitation at four ft. They also lost all references around four ft but regained them as they were

[37] The efficiency of the main rotor blades of an aircraft in the hover is improved with each knot of incoming wind gained through translation (aircraft moving horizontally across the ground or an increase in surface wind). Because of this movement of the aircraft through the air, turbulence and vortices are left behind and the flow of air becomes more horizontal which improves the efficiency of the rotor system. Improved rotor efficiency resulting from directional flight is called translational lift. At about 16-24 knots (depending on the size, area, and RPM of the rotor system) the rotor completely outruns the recirculation of old vortices and begins to work in relatively clean air. (CF Manual of Aerodynamics)

crossing the barrier. The difference is that their application of power was more gradual and steady and they did not pause or limit their application during the takeoff. However, as they only cleared the barrier by an estimated maximum of 10 ft, and with recorded ITT exceedences above 810 to 850ºC, they were also in an overweight and power deficit condition. The HUMS from the #2 aircraft recorded ITT exceedences greater than 810ºC for longer than five seconds on both engines during both the morning and afternoon takeoffs from the FOB as depicted in Table 6. While not conclusive, this analysis assumes that the similarly configured accident aircraft also recorded ITT exceedences in the morning takeoff.

		Above 810ºC	Above 830ºC	Above 850ºC
Morning takeoff	Left engine	10 secs	5 secs	
	Right engine	16 secs	9 secs	4 secs
Afternoon takeoff	Left engine	17 secs	15 secs	1 secs
	Right engine	15 secs	3 secs	1 secs

Table 6: CH146414 Engine ITT Exceedences for the morning and afternoon FOB takeoffs.

2.7.12 In summary, a review of interviews, CVFDR and HUMS data indicated that there were initial inadvertent inputs which initiated left yaw and right drift. A right cyclic input was made approximately six seconds before impact, the collective position was raised in three distinct stages and lowered once, as the aircraft’s heading transitioned from 221ºM to 199ºM before coming back to 207ºM at the time of impact. The staged application and slight decrease of collective were not efficient at generating vertical lift and are believed to have contributed, in addition to the overweight condition and lack of translational lift, to the accident aircraft’s loss of climb momentum. The right cyclic movement during the transition to the ITO procedure contributed to the right bank which resulted in an accelerating aircraft attitude towards the barrier. The fact that the #2 aircraft cleared the barrier is attributed to their smooth and constant application of collective, the additional power gained when they exceeded the ITT limits and the reduced AUW due to the 200-300 lbs difference in fuel load. It is assessed that neither aircraft could have successfully completed its takeoff and cleared the barrier without exceeding ITT limits.

2.8 CH146 Performance Charts

2.8.1 Certification

2.8.1.1 As indicated in section 1.6, virtually all certification approvals were managed and controlled by the CH146 Project Management Office as AETE's role was very limited. Research of AETE project files was limited to focus on performance testing and found a summary of the limited Cat I Experimental Test & Evaluation test results for the CH146 conducted from 1994 to 1996. The AETE

CH146 Cat 1 Testing Final Report[38] concluded that *"Within the scope of BHTC's Category I testing, the CH-146 showed excellent potential as a civil transport category helicopter. However, BHTC testing did not include any testing germane to the specific requirements of its intended military missions, therefore, the suitability of the CH-146 as a utility tactical transport helicopter in support of land forces or as a combat support helicopter in support of air forces could not be assessed."* The AETE report went on to recommend an additional 14 issues for further testing with the relevant five copied here:

a. mission specific testing to identify and define technical and human factor limitation of the CH-146 with respect to its intended military roles (para 4.01);

b. an evaluation of the visibility and accessibility of the CH-146's instruments, panels, displays and caution, advisory and warning annunciators for its intended military roles and crewing (para 4.15);

c. flying and handling qualities testing to the criteria of MIL-H-8051A[39] and ADS 33D [40] (para 4.18);

d. independent validation of the performance criteria of the Detailed Specification[41] (Ref 1-1) (para 4.19); and

e. a safety of flight crew workload assessment under mission representative conditions (para 4.22).

2.8.1.2 There was a variety of test plans covering various aspects of CH146 Cat II testing that were completed by AETE such as FLIR and NVG testing, among many others. It was the Project Directive for Cat II testing, Test Plan C, which could have captured the recommendations from the Cat 1 Final Report that originally tasked AETE with *"Validation of flight manual performance charts found in Section 8 of the flight manual which are not associated with the FAA civil certification."* Test Plan C was only one of many CH146 Cat II test plans carried out by AETE but this was the particular one that included performance testing and it was eventually cancelled due to personnel limitations, time constraints and conflicting project priorities. That decision was made by the flight test working group which included representation from the 1 Cdn Air Div, 1 Wing, WSM and AETE. No final report was produced and therefore performance charts unique to the CH146 were never independently validated by AETE. With limited testing and no validation completed, the CF accepted the civil Bell Model 412 charts as

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[38] AETE 10081-S40-9401 (Plans 3), PROJECT S40-9401 CH-146 CATEGORY I TESTING – FINAL REPORT, 2 May 1997.
[39] MIL-H-8051A: Helicopter Flying and Ground Handling Qualities.
[40] ADS 33D: Aeronautical Design Standard, Handling Qualities Requirements for Military Rotorcraft.
[41] Detailed Specification: BHTC Report 412-947-044A Detailed Specification for Canadian Forces Utility Tactical Helicopter (CFUTTH) Post CDR Edition.

the CH146 Griffon performance charts. The main point was that the CF did not conduct an independent check of performance data upon which certification was based. Investigators could not determine what processes or requirements were in place at that time to verify and validate aircraft performance data. Currently, the TAA/DGAEPM certification defines the level of flight testing required.

2.8.1.3 Interviews with key people from within the TAA, the OAA and the CH146 community also identified that the differences between an AFM and an AOI and the impact on military operational performance planning were not well known within these organizations. The aim of the AFM is to provide TAWD to safely operate the aircraft. There is no requirement to provide explanations on the performance charts or to direct aircrew to specific mission-oriented performance calculations for given environmental conditions. This information is normally included in an AOI, an SMM or provided during aircrew training. However, without such clear information for CH146 operations, the investigation revealed that there was no clear understanding of, or clear process for, calculating mission-oriented performance data from the AFM, other CH146 operation manuals or within the training provided to aircrew at the time before the accident. Ideal performance planning would have involved a review of the Hover Ceiling charts and the Critical Wind Azimuth charts in the AFM Section 4 to determine the allowable or maximum takeoff weight. This would then be followed by a review of the Cruise Performance and Hover Torque Required charts found in Section 8 of the AFM to determine the expected performance for their specific aircraft. While the Cruise Performance charts were not intended to provide hover performance data (power available or AUW in the hover) these were the charts available that could offer a close estimate. The fact that the AFM was not validated by the CF and that no AOI was created meant that there was little guidance on how to use these charts for mission-oriented performance planning. As previously explained, (refer to paragraph 1.6.5.8 dealing with the cruise performance charts), the sheer number and amount of charts to be carried and referred to in-flight also made it very difficult to calculate aircraft performance values while conducting operations. Eventually the development of the notebook with performance software easily enabled re-calculations in-flight for Afghanistan. However, at the time of the accident, performance planning could only be extrapolated from information within the AFM; with no clear directives on how to properly use the charts and with the high number of charts to actually use, there was a high risk for confusion, lack of understanding, misinterpretation and improper calculations.

2.8.2 AFM Charts: Confusion and Lack of Understanding

2.8.2.1 During post-accident interviews and the review of CH146 performance charts, the investigation found both confusion and a lack of understanding of the various charts found in the CH146 AFM by the technical and operational communities. Initial indications were evident during the post-accident CH146 AFM performance chart review that included the personnel from the OEM, the TAA and the OAA with representatives from DGAEPM (TH), DTAES, AETE, 1

Cdn Air Div and C Air Force Staff. During these meetings it became increasingly clear that, in addition to the errors and discrepancies found within the performance charts, the required knowledge for using the CH146 AFM performance charts was low and posed a high risk for improper and inadequate performance calculations. As indicated in the DTAES technical note in section 1.16, these issues included the origins and validity of the charts, incorrect charts and the placement of the charts within inappropriate sections of the AFM.

2.8.2.2 Discussions with TAA stakeholders revealed some confusion when dealing with the AFM charts. From the TAA viewpoint, as not all charts are developed using TAWD exclusively, it is the OAA staff, via the operational community, that should be able to identify issues with the flight manual. The technical staff is typically not trained in using the charts for flight planning and does not control how aircrew are trained or when and how aircrew use them. Should the operational community find issues, errors or discrepancies, it is incumbent upon them to report these to the TAA for resolution. It is understood that the technical staff within the TAA (WSM/DTAES) have the requisite knowledge and expertise to deal with technical airworthiness data, to answer or find answers to technical questions and to quickly learn and understand the issues if and when they arise. It is not expected or feasible for them to have in-depth knowledge of all performance charts when no issues have been raised by the operational community to focus attention on the subject. However, the investigation noted considerable confusion with the AFM charts during discussions between WSM and OEM specialists. This was further confirmed during additional post-accident meetings, exchange of email, telephone and in-person interviews.

2.8.2.3 This was equally apparent within the operational community; while some pilots and flight engineers were very knowledgeable and educated on the proper use of the AFM and the charts, a surprising number of aircrew showed difficulty in explaining the use of the appropriate charts, selecting the proper charts or conducting proper calculations. Several aircrew interviewed showed an inconsistent level of knowledge and understanding on using the AFM charts. Personnel interviewed from both the technical and operational communities confided that this confusion and knowledge gap existed and that it could have developed over many years, potentially beginning as far back as the CH146’s introduction to service.

2.8.3 AFM Charts: Section 1 and Section 4

2.8.3.1 The investigation found that the differences between Sections 1 and 4 of the CH146 AFM were not clearly understood by the 1 Wing aircrew interviewed. Section 1 includes limitations set by the OEM and/or regulator that shall not be exceeded. However, for the charts depicting performance levels in Section 4, sound airmanship and risk management principles suggest that going beyond these certified minimum-assured performance levels should only be done in carefully controlled circumstances. In situations where conditions are favourable (such as good visibility and weather) and other operational risks are controlled or minimized, operating beyond the depicted performance levels can be an effective use of the aircraft's maximum capability. Doing so in less than optimum conditions, such as at high HD and/or in the presence of obscuring phenomena, does place the aircrew and aircraft in an operating region with minimal or no safety or performance margins and this can significantly elevate the risk level. At times the military operational imperative may justify operations in this region, though this should be accepted and directed by the chain of command.

2.8.4 AFM Charts: Lack of Confidence

2.8.4.1 The investigation found a lack of confidence in the accuracy of the AFM performance charts within the CH146 aircrew community. In the span of the CH146 service life, in-flight aircraft performance was often much better and outperformed the values that had been calculated using the cruise performance charts, which are based on Min Spec engines. Over time, this led to gradual erosion in the confidence of the accuracy of the charts' information and this influenced the way crews were conducting power and performance calculations in preparation for their respective missions. This also led CH146 aircrew to question the validity of the charts and downplay the importance of completing detailed performance calculations. Several senior and experienced aircrew from within 1 Wing confirmed that this degradation of confidence existed but admitted that the issue had never been officially addressed or raised to the technical authorities. As explained, the TAA would have been unable to address these concerns when they had not been formally reported. This lack of confidence in the accuracy of the AFM charts resulted in their limited, and at times, inadequate and improper use during flight planning. With the mindset that the performance charts were incorrect or overly conservative, many crews reverted to using only the Weight-Altitude-Temperature (WAT) charts for mission planning.

2.8.5 AFM Charts: Performance Calculation Training and Improper Calculation Methods

2.8.5.1 Investigators also found deficiencies in the aircrew performance calculation training. A review of the training, details and methodology on using AFM charts for CH146 mission planning could not be found in the AFM or the SMM; additionally, an AOI did not exist to provide such details. Initial discussions and interviews with SMEs in 1 Wing headquarters revealed discrepancies and errors in calculation methods. Follow-on interviews with personnel from 1 Cdn Air Div and the CH146 training unit, 403 Helicopter Operational Training Squadron (HOTS) indicated that with pre-flight calculation duties primarily conducted by the FEs, their training was typically more detailed and comprehensive than that provided to pilots. Investigators discussed the AFM charts and performance calculations with several current and formerly qualified pilots and FEs. As these calculations were part of their typical pre-flight duties, the investigation found that the FE's were typically more proficient with the AFM charts. However the investigation found a wide range of experience and knowledge, from excellent to quite poor. Pilots received similar performance calculation training and, as this task was typically conducted by FEs, their knowledge and proficiency with the AFM charts was generally lower than that of the FEs. The range of experience and knowledge also varied. Overall, the investigation found that skill or knowledge in conducting proper calculations was lacking. This is not to suggest that all aircrew within 1 Wing could not conduct proper calculations. However, multiple interviews with former and current CH146 pilots and FEs from within the CH146 community found a surprising number of aircrew whose knowledge of conducting proper calculations had degraded and was either incomplete or erroneous.

2.8.5.2 As revealed in DFS interviews, some aircrew often used improper calculation methods as they incorrectly applied the WAT chart as the primary reference for mission planning. Many were not in the habit of consulting the IGE or OGE Hover Ceiling charts, Cruise Performance or Hover Torque Required charts to calculate aircraft performance and determine if they would have a sufficient power margin to conduct a mission. The investigation found that many CHF(A) crews based their aircraft performance planning, solely and erroneously on ***Figure 1-1A (WAT limitations for takeoff and landings and IGE manoeuvres, winds from -45 deg to 45 deg, 9 passengers of less)*** of the AFM or the similar WAT chart ***Figure 8-13***.

2.8.5.3 For the Hover Ceiling IGE/OGE charts, neither power available nor power required calculations could be derived using these charts. For power required calculations, calculations assume that the aircraft is operated with Min Spec engines, with zero wind, at a weight within the limit of the charts and, provided the charts depict a limit line. For the CH146 fleet and aircraft in general, it is very common for engines to perform well above Min Spec. With the CH146, for a given flight condition and ITT value where the engine is able to produce more power than Min Spec, the resultant aircraft power available will normally be higher; therefore, if an aircraft is operated with engines that perform better than Min Spec, power available will be increased. While an engine may operate better than Min Spec, the resultant increase in power available can be hampered and reduced by exceeding weight, temperature and altitude limits. As previously indicated, the presence of a positive or negative wind vector will reduce or increase power required. Combined, (the increase in power available with the reduction in power required) these factors will increase the power margin; this actual amount could not be calculated for the accident aircraft or for any CH146. Although not required by certification standards, neither the AFM nor the SMM contained a methodology for aircrew to determine the actual margin of power available above Min Spec power. Also, certain WAT charts in use at the time of the accident, such as ***Figures 1-1A, 8-11, 8-12*** and ***8-13*** did not include a limit line as depicted on the WAT chart ***Figure 1-1*** or on the IGE Hover Ceiling chart ***Figure 4-4***. In this scenario, the proper OGE Hover Ceiling chart should have been ***Figure 4-4 (sheet 3 of 11)***.

2.8.5.4 In addition, the SMM did not specify any minimum power margin to conduct a takeoff from a four ft hover IGE. There was no information to determine what percentage of additional power was required to go through translational lift. Only in the case of an MPTO was there guidance that directed a minimum power margin of 20% to be available above hover torque IGE. With the assumption that power available was always 100%, some CHF(A) CH146 aircrew interviewed in the conduct of this investigation also erroneously assumed that any hover torque value below 80% was acceptable to conduct the MPTO.

2.8.5.5 As performance calculations are normally conducted by the FE, and since the accident FE perished in the accident, investigators could not locate pre-flight calculations or determine with certainty which WAT chart was used by the accident FE. The #2 aircraft FE used the least restrictive WAT chart, ***Figure 1-1A***. Again, it is important to understand that the ***Figure 1-1A*** chart did not contain the note referring the reader to the Hover Ceiling charts, nor did it contain a limit line that guaranteed aircraft performance with Min Spec engines as depicted on ***Figure 1-1***. In addition, use of only the WAT chart ***Figure 1-1A*** was facilitated by the fact that the WAT chart ***Figure 1-1*** indicated all wind azimuths and for 10 passengers or more while WAT chart ***Figure 1-1A*** indicated -45^{o} to +45^{o} wind azimuths and 9 passengers or less. The indication of the number of passengers (10 or more or 9 or less) is a certification criteria but this was misunderstood by CH146 aircrew and erroneously led them to use ***Figure 1-1A***. Generally, performance planning stopped there and the IGE or OGE Hover Ceiling charts, Cruise Performance or Hover Torque Required charts were seldom used.

2.8.6 The investigation concluded that aircrew from both the accident and #2 aircraft referred to the AFM WAT charts (specifically ***Figure 1-1A***) to determine whether they would be able to safely takeoff from KAF as was common practice; and this was the extent of their performance planning. The WAT limit derived for the IGE takeoff out of KAF was 11,900 lbs, the aircraft’s certified maximum GW. The estimated aircraft weight for the takeoff out of KAF was 11,520 lbs, close to 400 lbs less than the WAT limit. This led the accident crew to believe, erroneously, that they had sufficient power available. For the takeoff out of the FOB, the density-altitude (see paragraph 1.7) had increased, requiring higher performance from the aircraft. Due to obstacles that were present, the takeoff required OGE performance and therefore reference to the applicable WAT chart for OGE operations. The WAT limit was 11,060 lbs. The estimated aircraft weight on takeoff from the FOB was 11,520 lbs, or 460 lbs overweight. Evidence indicates that both the accident and #2 helicopter crews assumed that, if they could depart from KAF (according to the WAT charts) and as long as they expended a sufficient amount of fuel to reduce weight, they would have sufficient performance to takeoff from intermediate stops. In this case, since their calculations for KAF gave them a 400 lb margin, they expected that the additional weight savings from the fuel burn en route would allow them to safely takeoff from the FOB. As previously indicated, interviews revealed that CHF(A) crews commonly used the WAT charts only and there was little use of or no reference to the Section 4 Hover Ceiling charts, which in most cases are more restrictive. The relevant OGE chart that should have been used was the OGE Hover Ceiling Chart, ***Figure 4 - 4 (Sheet 3 of 11)***, which showed a guaranteed Min Spec weight of only 10,000 lbs thus providing an estimate that the accident aircraft was close to 1,500 lbs over the Min Spec weight. With such an apparent and drastic overweight condition, the investigation concluded that the accident crew did not consult the appropriate charts, power margins were not determined, performance calculations were conducted for the takeoff from KAF only and none were completed for intermediate stops or the accident FOB.

2.8.7 These deficiencies in training, the improper calculation methods, the lack of confidence in the accuracy of the charts and the overall lack of knowledge with respect to the expected engine performance paved the way for this accident as well as ITT and/or other exceedences to occur in Afghanistan’s high density altitude environment.

2.9 Inter-Turbine Temperature Exceedences

2.9.1 Over the span of the CH146 service life on both domestic and deployed operations abroad, the aircraft was rarely operated at the extreme end of its performance limits as it was in Afghanistan. Interviews with various current and former CH146 qualified aircrew indicated that during most operations, the CH146 was historically and generally flown within the Qm band of limits and aircrew rarely encountered situations where ITT became the limiting factor. The normal ITT operating limitation for CH146 twin-engine operations is 810ºC with a five second transient limit to 940ºC; the AFM also prohibits intentional operations above these limits. After the accident and as part of the regular HUMS data analysis supporting routine maintenance, the WSM identified that the ITT limit of 810º-940ºC for more than five seconds was exceeded over 1,120 times in Afghanistan between Dec 08 and Nov 09. When the CH146 first entered theatre in Dec 08 the aircraft would likely have been Qm or AUW limited. With the onset of the hot summer season and with elevated OATs, the aircraft would have become temperature limited or ITT limited. As a result, the rate of exceedences significantly increased. However, with the historical expectation that the aircraft was Qm limited and with minimal use of the OGE charts for flight planning, it would have been difficult for aircrew to anticipate that ITT would become the limiting factor. Although these exceedences were reported to maintenance personnel and recorded, they were not reported to Flight Safety personnel or entered into the Flight Safety Occurrence Reporting System.

2.9.2 Maintenance Actions

2.9.2.1 Interviews with WSM staff as well as with CHF(A) aircrew and personnel revealed a difference between operator and technical manuals. As is the case for all aircraft, technical limitations identified in maintenance documentation are not necessarily identical to operating limits. However, common practice should be to report exceedences of published operating limits to the maintenance and/or operational authority. Apart from the stated ITT limits, there was no direction in the AFM or the SMM concerning ITT exceedences and the required aircrew or maintenance actions. The maintenance personnel referred to the CH146 maintenance manual C-14-108-000/MF-001, page 619, Figure 604 for guidance. Some aircrew reported that after initially identifying to maintenance personnel that they had exceeded ITT limits, no maintenance activity was carried out. For the vast majority of these exceedences, the maintenance manual directed “no maintenance actions required” and/or “maintenance recording required” meaning the only actions taken were to record the event in the aircraft record set. Based on the assumption that no maintenance actions were required some aircrew believed that the exceedences did not constitute reportable Flight Safety occurrences. Testimony indicated that reporting ITT exceedences directly to maintenance vice Flight Safety became the informal SOP; this reporting procedure gradually diminished to the point where no ITT exceedences were reported. This and the lack of information within the AFM concerning ITT exceedences contributed to the lack of reporting by aircrew, which allowed the exceedences to continue to occur without any maintenance, operational or flight safety authorities to have knowledge, oversight or be in a position to deal with this issue.

2.9.3 Interpretation of Limits

2.9.3.1 The number of ITT exceedences was exacerbated by several CHF(A) and 1 Wing aircrews’ interpretation of the ITT limitations found in the AFM. The ITT limit is 810ºC with a five second transient limit to 940ºC, but the AFM CAUTION states that *“intentional”* use of ITT above 810ºC is prohibited during normal operations except during start. This raised two issues. First, Notes, Cautions, or Warnings tends to be advisory in nature, whereas limitations are mandatory. The proper terminology for warnings, cautions and notes is defined in the Foreword page i of the AFM and are used to emphasize important and critical instructions.[42] This is not uncommon in CF AFM/AOIs. This specific limitation was embedded in the Caution depicted after all ITT limits and may have been perceived by aircrew as advisory information only. Second, the investigation found that CHF(A) aircrew did not hesitate to regularly use and exceed the transient ITT limits. When questioned on their interpretation of ITT limits and intentional operations above 810ºC, several aircrew stated they never *“intended”* to operate beyond 810ºC but operational pressures and climatic conditions often required the exceedences. Since there was no initial intent to exceed limits, several aircrew did not consider these exceedences as reportable Flight Safety occurrences. Aircraft limits are often set to consider the negative effects of use, fatigue, and service life on aircraft components and exceeding established limits thus has a direct impact on these factors. Understanding this,

[42] The AFM definitions are copied as follows: WARNING: An operating procedure, practice, etc., which, if not correctly followed, could result in personal injury or loss of life. CAUTION: An operating procedure, practice, etc., which, if not strictly observed, could result in damage to or destruction of equipment. NOTE: An operating procedure, condition, etc., which is essential to highlight.

aircrew will normally avoid exceeding aircraft limits in power-limited conditions unless facing rare and extreme conditions requiring the maximum performance available. The large number of ITT exceedences clearly indicates that the aircraft was power-limited in Afghanistan. However this number also indicates that aircrew did not hesitate to regularly use and exceed the transient ITT limits. Given witness testimony and statements from aircrew in CHF(A), the investigation revealed that several aircrew were not aware of the negative effects on component service life and regularly turned a blind eye to the 810º-940ºC five second transient limit. In this case, their justifications were based on the stated extremely high importance of the mission in Afghanistan, their own perception of operational necessity, their lack of awareness concerning the negative effects on component service life, and the perception of a lack of maintenance impact.

2.9.3.2 As previously discussed, the CH146 was often Qm limited and aircrew were seldom dealing with ITT as the limiting factor. In order to mitigate the risk of over-torque and to avoid exceeding a Qm limit, the SMM included directions to call out Qm during takeoff procedures. Standard crew duties detailed in Table 1-1 indicated that the NFP “was *to advise when power setting is 80% Qm (mast torque) and above in increments of 5% and approaching 100%; and to start timing so as not to exceed the 5 min limit above 81% Qm*.” Such detailed calls were not included for ITT limits. A review of the SMM only found a general statement indicating that the NFP should crosscheck systems and instruments. There was no specific reference to calling ITT limits on takeoff. The CH146 community continues to apply torque margin however, through a somewhat complicated method of trying to equate engine ITT limits to torque values, and using those for go/no-go decisions. This approach is not recommended and a method should be developed for flight planning that can account for either environment, without requiring the conversion of actual limits into surrogate values, such ITT into torque margin. Normally this could be simplified greatly if the aircraft had an integrated power display in the cockpit showing a “first limit” indication, and also providing situational awareness of the margin remaining to the first limit. However, the CH146 does not have this capability.

2.9.4 In summary, while ITT exceedences were initially often reported to maintenance personnel, follow-on maintenance action was not always required. After the accident, the CH146 WSM staff investigated these exceedences and discussed them with the OEM and, although the frequency of the exceedences was concerning, no additional maintenance action was required outside of the maintenance practices already existing. The required operational action was that the exceedences had to stop and that proper planning needed to be carried out. Routinely exceeding the ITT limits should have been a clear indication to the aircrew that they were repeatedly going beyond the engine power limited AUW capabilities of the aircraft. DFS interviews confirmed that CH146 aircrew had rarely operated in conditions where ITT was a limiting factor or been exposed to operating near ITT limits. A review of the SMM found little guidance for monitoring ITT limits during takeoffs. However, the large number of ITT exceedences demonstrated the aircrew’s acceptance to regularly exceed published limitations. Further investigation revealed confusion among the aircrew and maintenance communities’ understanding of the differences between operational limitations, maintenance limitations and the potential negative effects on an aircraft component’s service life when these are exceeded.

2.10 Post-accident Performance Calculations

2.10.1 The review of performance calculations indicate that both aircraft were operating in an area of power deficit within the power curve as depicted in Figure 3 of Annex B: Aircraft Performance Definitions. A significant factor that must be taken into consideration is the method used to calculate the aircraft’s performance capability for each mission. Aircraft performance can be determined for either torque or engine temperature limitations. The CH146 community, having customarily operated in torque-limited environments, typically used a performance planning approach based on torque margins. On the day of the event, given the environmental conditions at the FOB, a different planning approach was required as the aircraft was limited by engine temperature and not by the torque margins.

2.10.2 Performance Calculator Software

2.10.2.1 As described in section 1.19, the Performance Calculator planning software was developed to provide an estimate of aircraft power available under given environmental conditions. The software provided an estimate only. Screen captures of the Performance Calculator software output for both aircraft are depicted in Annex K. Using the applicable environmental conditions and aircraft data for the FOB takeoff, Table 7 presents the software estimated power available, maximum takeoff weight and shows the difference with the AUW. [43]

Aircraft	Estimated Power available		Maximum Takeoff Weight	Estimated AUW
CH146434	IGE	89.6% Qm	11,683 lbs	FOB required OGE takeoff
	OGE	**89.6% Qm**	**10,776 lbs**	**11,520 lbs**
CH146414	IGE	88.9% Qm	11,683 lbs	FOB required OGE takeoff
	OGE	**88.9% Qm**	**10,951 lbs**	**11,200 lbs**

Table 7: Software performance - Estimates Only.

2.10.2.2 Analysis of historical daily PACs revealed that both engines from the accident aircraft were performing better than Min Spec and that they had a slightly higher margin of performance than the #2 aircraft engines. Based on HUMS and FDR data, the accident aircraft reached an ITT of 840º-850ºC on takeoff, 30º-40ºC above the allowable maximum continuous twin-engine limit of

[43] The software is not based on all of the AFM charts that were in effect at the time of the accident. Some of those charts have since been replaced and newer ones (based on FAR 29 Cat B performance) were added which may permit an increase in performance. Therefore, the weights and Qm values quoted here from the software **are estimates only** for comparison with the #2 and accident aircraft. These indicate what was authorized with the software, and not what the aircrew could have or should have derived at the time of the accident.

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810ºC. As depicted in Table 6, the #2 aircraft recorded ITT exceedences above 810ºC for more than five seconds during its takeoff out of the FOB proving that it too was in an overweight condition.

2.10.3 Annex C depicts the WAT and Hover Ceiling charts that were available and the calculations (estimates)[44] pertinent to the environmental conditions present on the day of the accident for the takeoff out of KAF and for the takeoff out of the FOB. Annex D depicts the Cruise Performance chart calculations (estimates) and Annex E depicts the Torque Required to Hover calculations (estimates). The Qm values derived from the AFM WAT and Cruise Performance charts are representative of an aircraft with Min Spec engines.

2.10.4 KAF Takeoff

2.10.4.1 Performance data for the afternoon takeoff out of KAF resulted in the values in Table 8. (Using and interpolating between the 2,000 and 4,000 HP cruise performance charts - see Annexes C, D, and E.)

KAF Takeoff (HP 3,520 ft; OAT 42ºC; AUW 11,520 lbs)	
WAT IGE limit	**11,900 lbs**
WAT OGE limit	11,300 lbs
IGE Hover Ceiling limit	**10,600 lbs**
OGE Hover Ceiling limit	10,200 lbs
Hover torque required OGE	92% Qm
Hover torque required IGE	**78% Qm**
Power available	**77% Qm (-1%)**

Table 8: Performance data for the KAF takeoff (IGE values could be used)[45]

2.10.4.2 Given the ambient conditions for the takeoff at KAF and using the Cruise Performance charts, the power available for an aircraft with Min Spec engines would have been 77% Qm. Using the Hover Torque Required charts, the Qm required for an aircraft with Min Spec engines would have shown 78% Qm for hover IGE. This 1% deficit indicated that the aircraft was limited by engine power (and therefore ITT) and not limited by Qm. The fact that Qm required was greater than Qm available indicates the aircraft was in an overweight condition. Max AUW at KAF (for 3,520 ft and 42°C) was 11,415 lbs for IGE; the actual aircraft weight was 11,520 lbs, 105 lbs overweight. Although overweight for the takeoff out of KAF, it would only have required a slight ITT exceedence to get airborne. The reason for which they were able to get airborne out of KAF without exceeding the ITT limit could be explained by several factors

[44] The calculated values in paragraphs 2.10.4.and 2.10.5.were derived using the charts of the AFM Ch 2 dated 2009-02-20. The values depicted within the Annexes may not be exact due to software limitations or the width of the lines in trying to align exact values.

[45] The importance of this table is to show the weight differences between the AUW of 11,520 lbs and the calculated limits in bold. The -1% is the difference between the Hover Torque Required IGE and the Power Available.

such as engines operating at better than Min Spec (which could not be determined), wind effects, lower hover altitude used in the transition to forward flight or smoother aircraft handling.

2.10.5 FOB Takeoff

2.10.5.1 Performance data for the afternoon takeoff out of the FOB resulted in the values in Table 9. (Using and interpolating between the 4,000 and 6,000 HP cruise performance charts - see Annexes C, D, and E.)

FOB Takeoff (HP 4,675 ft, OAT 39ºC, AUW 11,520 lbs)	
WAT IGE limit	11,750 lbs
WAT OGE limit	**11,060 lbs *(-460 lbs)***
IGE Hover Ceiling limit	10,300 lbs
OGE Hover Ceiling limit	**10,000 lbs *(-1,520 lbs)***
OGE AUW	9,600 lbs
OGE AUW @ 23 ft	**9,800 lbs (*-1,720 lbs*)**
Hover torque required IGE	78% Qm
Hover torque required OGE	**93% Qm**
Power available	**76% Qm (-17%)**

Table 9: Performance data for the FOB takeoff (OGE values should have been used)[46]

2.10.5.2 Using the Cruise Performance charts, the power available with Min Spec engines was a maximum of 76% Qm. The Hover Torque Required charts identified 93% Qm as the power required to hover OGE at the FOB. This represents a performance deficiency of 17% below what was required for hover OGE which, had these calculations been made, would have necessitated a further review of environmental conditions, aircraft performance and the mission. A review of the CH146 operating manuals found little guidance on how to use performance calculations to support mission acceptance or substantiate mission rejection. However, RCAF flying regulations stipulate that the aircraft must be flown according to its published operating limits (as per AFM or AOIs), thus providing ACs the required authority to accept or reject missions that can accomplished within these limits.

2.10.5.3 The takeoff from the FOB was much more challenging on a performance perspective from both the KAF takeoffs and those conducted that morning. Given that the barrier was eight ft high and the SMM required a 15 ft clearance over the obstacle, the ITO procedure (applicable in situations involving a DVE, such as brown-out) required a 23 ft hover capability. The CH146 WSM and AETE sanctioned a Hover Performance Project where an assessment of the accident was performed. Based on the AETE flight test results, it was

[46] The importance of this table is to show the weight differences between the AUW of 11,520 lbs and the calculated limits in bold. The -17% is the difference between the Hover Torque Required IGE and the Power Available.

determined that the aircraft was in fact capable of hovering IGE in the FOB conditions at 11,520 lbs (Min Spec with no margin), however for the same conditions the OGE hover capability would have been 9,600 lbs. The OGE Hover Ceiling chart indicated a max OGE weight of 10,000 lbs. Using the effects of the skid height chart for a 23 ft departure shows a max AUW of 9,800 lbs, indicating that the aircraft was 1720 lbs overweight for the intended departure.

2.10.6 The evidence of the overweight condition due to fuel and passengers, the review of performance calculations, and the ITT exceedences recorded on both aircraft indicate that both the accident aircrew and the #2 aircrew were operating the aircraft/engines well beyond their normal operating limits. Although new charts were used in the development of the software which provides increased performance over the charts that were available at the time of the accident, both the new charts and the software reveal that neither the accident aircraft nor the #2 aircraft would have been able to takeoff without exceeding ITT limits and that neither aircraft had power available to attempt an OGE takeoff given their estimated AUW.

2.11 Organizational Issues

2.11.1 CH146 Deployment to Afghanistan

2.11.1.1 It is important to note that the CF was not the only nation to operate helicopters in Afghanistan. A wide spectrum of helicopter types from other nations, including variants of the Bell 412, operated in the Afghan theatre. All were subject to the hostile military and meteorological environment including operations in DVE and in high, hot and heavy flight regimes. Several staff checks had been completed to assess the various options in deploying the CH149 Cormorant, the CH124 Sea King or the CH146. With the CH146 already fulfilling the role of being the CF’s tactical aviation helicopter, selecting the CH146 was the logical solution. This facilitated the transition into combat operations and the integration with the Canadian Army and Allied land forces in theatre. In addition, the selection of the CH146 offered the CF the ability to effectively support the newly acquired Chinook and its missions in theatre. Essentially, the CF was tasked with a mission to deploy tactical aviation assets into a combat theatre; the CH147D Chinook and the CH146 Griffon were the best capabilities that the CF had available to support this mission. With that, the RCAF chain of command, including operational and technical authorities, had the full expectation that the helicopters would be flown within stated limitations detailed in the aircraft’s respective flight manuals.

2.11.1.2 A review of the various pre-deployment decision briefings conducted prior to the deployment into Afghanistan revealed that the CH146 capabilities and limitations were presented by experienced aircrew but focussed mainly on its range and payload capacities. The limited CH146 performance data that was presented was based solely on ***Figure 8-11 WAT chart, all azimuths*** (Annex C pg 4/6) of the AFM. As previously indicated in paragraph 1.6.5, the WAT Charts only determine the maximum allowable weight and maximum HD for takeoff, landing and IGE/OGE hover operations. The Hover Ceiling, Cruise Performance or Hover Torque Required charts were not referenced and, therefore, critical aircraft performance information was not presented. Given the high HD operating environment, the overall expectation was that the aircraft would be power-limited and that performance would be limited by parameters such as Qm. However, the brief presented little information concerning power performance including Qm or ITT. With the briefed aircraft capabilities and limitations based solely on the ***Figure 8-11 WAT chart***, and while CH146 power performance may not have been presented, the chain of command could have been left with the impression that the CH146 performance would be significantly better than it actually was. On one hand, despite the challenges of operating at high OATs and HDs, the Griffon was suitable and very effectively employed within operational limits for operations in Afghanistan for certain specific missions (e.g. passenger transport in winter months when OAT was lower, Intelligence Surveillance and Reconnaissance (ISR) missions, Escort, and Fire Support roles when properly managed.) On the other hand, passenger transport or other utility flights in such extreme environmental conditions, with OATs and HDs, combined with flights conducted to very austere unprepared surfaces, at high elevations or with the potential for DVE, could prove challenging and extremely difficult to accomplish. Nonetheless, the chain of command had the full expectation that the aircraft would be operated within its performance limitations.

2.11.1.3 1 Cdn Air Div uses the Record of Airworthiness Risk Management process to identify and mitigate risk. *RARM - CH146 2008-001 Combat Configuration for Afghanistan* was released on 03 March 2008, well before the CH146 deployment and the accident, to assess the impact of conducting flying operations without certain aircraft components. With an understanding of Afghanistan’s challenging environmental conditions, the aim of the RARM was to reduce the basic aircraft weight and tailor its configuration to afford greater flexibility, enhance mission accomplishment and mitigate the inherent adverse HD impacts. This initial RARM proposed the removal of the basic survival kit, IFR equipment, the paper copy of the AFM, and daytime anti-collider lights; subsequent versions of the RARM eventually led to the removal of the cargo doors. Included in the RARM were mitigation strategies such as flight operations to be conducted using the principle of section integrity (flying as a pair of helicopters), under VMC, under the cover of darkness to the maximum extent possible and above the small arms threat. The RARM did not initially address an expansion to operating limits.

2.11.1.4 At the tactical level as early as October 2008, initial RARMs for CH146 operations in Afghanistan had been drafted to identify and mitigate the risk of helicopter employment, mission flight profiles and weapon employment in a high threat environment. These had been drafted as some unit-level officers saw a need to identify these risk factors and to ensure that these were in line not only with the CF’s Airworthiness Authority’s (AA), OAA and TAA acceptable levels of risk, but also with other allied tactical aviation forces in theatre. These proposed

RARMs included operational issues such as operations in low illumination, countering rocket-propelled grenade/indirect fire/small arms fire, operations at high HD, mountainous terrain, operations in mixed formations, and operations in small/dusty FOBs. Discussion with 1 Cdn Air Div Operational Airworthiness staff in addition to a review of their website and RARM database revealed that these RARMs had not been staffed to 1 Cdn Air Div. Despite the intent behind these proposed RARMs and the mitigating actions identified, this accident occurred at a very high HD, mid-day in July and with an increased passenger and fuel load; high, hot and heavy.

2.11.1.5 The investigation revealed that Roto 6 had stopped flying passengers as early as February. However with the arrival of Roto 7 at the beginning of the summer season, as the temperature rose steadily during the month of May and as they were trying to deal with the associated issues with the Griffon, CHF(A) made an attempt to shift the majority of its operations at night and succeeded partially. In that month, CHF(A) led several multinational deliberate operations in the Canadian Area of Responsibility (AOR), thereby allowing the bulk of the flying activities to be conducted at night and mitigating the effect of increasing temperatures. This was also made possible because CHF(A) could obtain support from an allied nation for the delivery of specialized capabilities needed at the point of insertion and because this also aligned with the Commander JTF-A’s priorities for that period of time. However in June, the allied nation reassigned their support elements and the Campaign Plan entered a new phase that required predominantly daytime support. Consequently, CHF(A) had to transfer the bulk of its flying back to daytime missions.

2.11.1.6 CHF(A) adapted and contributed significantly to the change in the Campaign Plan and the shift to daytime operations. However this shift and the accident, as it occurred in the high, hot and heavy regime, revealed a breakdown in communication between the commander’s strategic level intent to mitigate the CH146 performance in the high, hot and heavy regimes and the day to day operations at the tactical level. To mitigate the CH146 performance in the high, hot and heavy regimes and the limited on board self-defence/survivability equipment issues, specific operational parameters were identified during the pre-deployment briefings regarding where, when and how the aircraft was to be operated. Considerations included operating with reduced fuel loads, operating at night using NVGs and avoiding conditions that would require the aircraft to operate at high AUWs and high HDs. Although these mitigating measures were presented during the pre-deployment briefs, the investigation could not identify any strategic level documentation, including the OP ATHENA CHF(A) Concept of Operations (CONOPS), that directed implementation of these detailed measures at the tactical level.

2.11.2 Lack of Operational and Strategic Level Support

2.11.2.1 At the start of the deployment, operational and strategic level direction and support for certain issues was often incomplete or not available. Tactical level solutions and decisions were required often with extremely short notice and with short timelines. One example of this was the identification of the OAT limits affecting CH146 operations. Due to increases in the OAT above the CH146 operating limit of 45^{o}C (51.7 minus 2 degrees per 1000 ft elevation) that were forecasted to occur within a week, the unit CO approached the WComd and advised of a potential impact to CH146 operations. CHF(A) was compelled to request short-notice support from the WSM to resolve this issue. Two 1 Cdn Air Div messages (UNCLAS COMD 077 and UNCLAS COMD 559) as well as the associated RARM (*RARM-CH146-2009-12*) were signed on 19 June 2009 by the Commander 1 Cdn Air Div authorizing CH146 operations up to 5ºC above the normal maximum OAT limit under specific risk-mitigating conditions.[47] A second example surfaced when it was discovered that the CH146 had exceeded its VNE on several occasions while conducting Chinook escort missions. With technical support from the WSM, 1 Cdn Air Div released two messages (UNCLAS COMD 556 and UNCLAS COMD 565) authorizing an increase to the VNE envelope.[48] From the technical and operational staff's perspective, significant effort and resources were expended to resolve these issues once they were identified. For those in theatre, these issues should have been resolved prior to deployment.

2.11.2.2 Interviews with WSM staff and aircrew in theatre revealed that while some performance limitations were identified prior to the deployment, details of associated challenges such as mission planning, operating speeds and operating temperature limits as well as potential and specific solutions to these challenges, were not addressed. It is not expected that higher headquarters technical or operational level staff would be cognizant of, or could have anticipated, tactical requirements that were never raised by the operational community prior to deployment. It was only anticipated that operations would be conducted by trained military professionals within aircraft limits that would be adhered to. However, personnel and resources at the tactical level in theatre faced an increasingly demanding operational tempo in a challenging and hostile environment. Operational and environmental issues surfaced, such as the expectation to fly faster than the VNE to escort the Chinook or the necessity to operate above certified OAT values. The lack of resolution on certain issues left operators in an unfavourable situation where they were expected to react to issues in theatre as they arose.

2.11.2.3 Under normal circumstances (i.e. domestic operations, non–combat environments), there are CF and RCAF technical, operational and strategic level headquarters responsible for airworthiness and administrative procedures that are called upon to address and resolve issues related to aircraft limitations and

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[47] UNCLAS COMD 077, COMD AUTH CH146 DEPLOYED OPS ABOVE OAT LIMIT dated 19 Jun 09, UNCLAS COMD 559, POAC: CH146 DEPLOYED OPS ABOVE PUBLISHED AOI OAT LIMITS dated 06 Aug 09, and RARM-CH146-2009-12 - Deployed Operations Beyond CH146 outside Air Temperature Limitations.

[48] UNCLAS COMD 556, CH146 POAC: OP ATHENA INCREASED VNE LIMITS dated 14 Jul 09, and UNCLAS COMD 565, CH146 POAC: OP ATHENA INCREASED VNE LIMITS dated 05 Aug 09.

operational challenges. At the operational level headquarters, A3 Maintenance Maritime and Tactical (A3 Maint Mar Tac), comprised of only five personnel, is responsible for technical and maintenance issues for the CH146 as well as the CP140 Aurora, CH124 Sea King, and the new CH148 Cyclone. The A3 Tactical Aviation (A3 Tac Avn) cell within 1 Cdn Air Div is comprised of only six personnel and they are the subject matter experts for CF Tac Avn matters responsible to the Commander 1 Cdn Air Div for Tac Avn Force Generation (FG). Their core activities include the coordination of standards, training, personnel and resource management as well as operational airworthiness efforts. In addition, they provide extensive input by coordinating emerging issues such as acquisition projects like the CF Medium-Heavy Lift Helicopter (MHLH). (Of note, there were only three personnel in the A3 Tac Avn cell at the time of OP ATHENA and one Major was deployed. The increase to six personnel occurred in 2011 when MHLH positions were established.) The Combined Air Operations Centre (CAOC) is responsible for Force Employment (FE) issues but again, there are limited personnel within the CAOC with CH146 experience available; they often rely on A3 Tac Avn and A3 Maint Mar Tac for FE support.

2.11.2.4 On the technical side at the strategic level, the CH146 WSM Section, DAEPM(TH) 6, comprised of approximately 30 personnel, is responsible for the maintenance policy, in-service support, engineering support, and technical airworthiness of the CH146 Griffon Helicopter fleet. For FE support at the strategic level, there were limited personnel within the offices of the CDS, C Air Force Staff, the Strategic Joint Staff or within the Canadian Expeditionary Force Command (CEFCOM) with specific aircraft experience and knowledge to provide continued support for individual aircraft fleet issues or deployments; they also often rely on the specific aircraft WSM or 1 Cdn Air Div A3 cells for support.

2.11.2.5 The technical, operational and strategic level staffs strive in all operations to provide the best support possible within their sphere of influence and abilities. To ensure effective oversight and planning support for operations, it is essential that an adequate amount of subject matter experts (SMEs) are available, involved, and empowered to make appropriate decisions regarding the platform and mission in question. With the reality of manning shortages and reductions in headquarters at all levels, it was and will be, essential that the RCAF ensure that more time is taken to consult the right SMEs or that an extra level of approval be instated where ambiguity exists in dealing with emerging issues such as aircraft performance capabilities prior to deployments. These SMEs must be available and in sufficient numbers to help resolve issues as they arise during deployments.

2.11.2.6 The Afghanistan mission proved to be the largest international deployment that the RCAF has had to face in several decades. In this case, the operational tempo and the continuous requirement to have aviation assets available to support and protect ground forces placed tremendous pressure on the Air Wing to keep the CH146 serviceable and flying. Investigators could only conclude that while the technical, operational and strategic level staffs were knowledgeable, professional and committed in supporting operations, several factors contributed to hamper the amount of support that they provided. This included the pressure to deploy, the short timelines faced by the CH146 community from initial notification to deployment onward to reaching operational capability, the operational pressures faced in theatre and most importantly, the limited number of specific personnel in key technical, operational and strategic level headquarters, such as in CEFCOM, C Air Force Staff, A3 Tac Avn, A3 Maint Mar Tac and CH146 WSM cells, to effectively support CF and RCAF FE activities.

2.11.3 CH146 Statement of Operating Intent

2.11.3.1 The SOI is normally a high level planning document typically used in the acquisition phase for a major project or capability. In this case, the CH146 SOI describes how the CF intends to use the CH146 Griffon and is used as the basis for continued analysis and development. It is considered a living document and will undergo amendments during the service life of the CH146. The SOI version 1.0 was dated 19 Sept 2008 indicated that it had been created well after the acquisition of the CH146. The CH146 SOI stated that the maximum HD limitation for the maximum gross weight of 11,900 lbs was 4000 ft HD and that operating at HD up to 14,000 ft, which it can, was possible at weights less than 11,900 lbs. The short-term solution for reducing the CH146 AUW and adapting a “combat configuration” was addressed with the creation of *RARM - CH146 2008-001 Combat Configuration for Afghanistan*. The long-term solution *“to increase the density altitude envelope for all-up weight operations”* required a review of the environmental limits stipulated in the SOI and the anticipated operating areas for the CH146; historical environmental and meteorological data from Afghanistan should have been considered prior to the CH146 deployment. The Canadian Army had been operating in Afghanistan for some time and a considerable amount of environmental and meteorological data was available to properly assess CH146 performance in that environment. However, despite this data and the efforts made to improve CH146 performance and expand the operating envelope in the multiple RARMs and POACs produced by the OAA or TAA, nothing specifically addressed expanding the CH146 performance in the high HD environment. Neither the long-term engineering solution to increase the HD envelope for AUW operations nor the environmental limitations offered in the SOI were addressed, amended or increased. The fact that possible future requirements were highlighted in very broad detail did not represent a tasking to any organization to take action to expand the performance envelope nor did it define the conditions specific for Afghanistan. Had this document been used and developed into a formal tasking it would still have had required more detail on exact mission roles and profiles.[49] Additionally, had this requirement been formally staffed to the CH146 WSM, the WSM and the OEM could have been engaged to resolve the issue. Regardless, the investigation found that the long-

[49] Note that the requirement for operating at Max GW up to 4,000 ft Hp at 35°C (7,000 ft Hd) was met by the MB-Z60 supplement for IGE that was created after the accident.

term solution to increase the HD envelope for AUW operations had not been resolved.

2.11.4 Issues such as OAT limits, VNE and ITT exceedences, were identified by personnel in theatre, raised by WSM staff or as a result of this flight safety investigation and ultimately resolved with support from the technical and operational staffs within the CF. Investigators could not identify why environmental and operational issues such as the expansion to OAT operating limits and VNE to conduct the Chinook escort missions had not been addressed prior to deployment. While the amendment of the SOI could have been an oversight, such issues affecting or limiting the CH146 performance and operations should have been addressed and resolved prior to their deployment to Afghanistan. Investigators found that the limited number of personnel in key technical, operational and strategic level headquarters contributed to a lack of oversight and planning support from higher headquarters during the preparation and planning phases of the CH146 deployment to Afghanistan.

3 CONCLUSIONS

3.1 Findings

Note: All findings include references to the applicable paragraphs in Section 1, Section 2 or the Annexes of this report.

Findings concerning the accident flight:

3.1.1 The crew was medically fit, qualified, current, and properly authorized to fly the mission. (1.5.1, 1.13.1)

3.1.2 Anticipating a dustball and high power requirement, the accident crew agreed to conduct an MPTO followed by an ITO. (1.1.3, 2.6.1, 2.6.2)

3.1.3 During the takeoff, the creation of an intense dustball contributed to a DVE that severely impeded the FP’s and FE’s ability to detect drift and ultimately the FP’s ability to correct the unintended drift, to see and to avoid the barrier. (1.1.4, 2.1.3.2, 2.1.4)

3.1.4 The FP suffered a loss of situational awareness during the takeoff due to the rapid and numerous changes in his focus during the 10 seconds prior to impact as he attempted to stabilize the aircraft and climb away. (2.3.1.1, 2.3.1.2, 2.3.3, 2.7.6)

3.1.5 During the takeoff, while cross-checking the ITT gauge, the FP lost visual references in the dustball. (1.1.4, 2.3.1.1, 2.3.2.4)

3.1.6 During the takeoff, while cross-checking the ITT gauge, the FP reduced power which reduced the helicopter’s climb momentum and inadvertently made a right cyclic input that exacerbated the right drift. (2.3.1.1, 2.7.2, 2.7.5, 2.7.7, 2.7.8, 2.7.9)

3.1.7 The FP employed the SMM recommended procedure of setting a flat pitch attitude on the ADI, which exacerbated both forward and unintentional right movement, causing the helicopter to drift forward and to the right. (2.6.5, 2.7.2, 2.7.8)

3.1.8 The aircraft collided with the barrier at the helicopter’s one to two o’clock position, yawed left, quickly rolled onto its right side, and immediately caught fire. (1.1.4, 1.3.1, 1.12.1, 1.14.1.1, 2.4.3)

3.1.9 The total flight duration from skids clear of the ground to impact with the barrier was under 10 seconds. (2.3.1.1)

3.1.10 The fire developed very rapidly, precluding the pilots from rendering assistance to the personnel trapped in the rear cabin area. (1.1.5, 1.14.1.1, 1.15.4.1, 2.4.3)

3.1.11 The Engine Fire checklist and Emergency Ground Egress procedures were committed to memory but it is likely that the actions were simply omitted in the stress and confusion of the situation. (1.6.7.1, 2.4.2)

3.1.12 The fatally-injured crew members’ egress was likely impeded by a combination of impact injuries, physical obstructions or restrictions to egress and smoke, fumes, and gases from the intense post-crash fire. (1.13.5.1, 2.5.1, 2.5.5, 2.5.6, 2.5.7)

3.1.13 The forces of impact were likely survivable. The causes of death were directly related to the post-crash fire. (1.13.5.1)

3.1.14 The aircraft sustained A category damage and was destroyed. (1.3.1)

Findings concerning the accident FOB:

3.1.15 There were no standards published for dust or fire suppression within the Afghanistan theatre of operations. The accident FOB was considered austere, not Canadian-controlled, and did not employ any dust or fire suppression measures. (1.10.3, 1.10.4, 2.1.2.1)

3.1.16 While some nations implemented mitigating measures for helicopter operations in FOBs considering dust and fire suppression criteria, CHF(A) training and flying orders did not. (2.1.2.2)

3.1.17 The selection of an alternate landing site within the FOB was inconsequential to the creation or intensity of the dustball; however, the lack of dust suppression methodologies and the poor sand conditions combined to create a DVE that eliminated the crew’s visual references. (2.1.3.2, 2.1.4)

Findings concerning crew training:

3.1.18 There is no formal or dedicated training for helicopter operations in a Degraded Visual Environment (DVE), either in whiteout/snowball or brownout/dustball, at 3 CFFTS or in the RCAF. (1.5.3)

3.1.19 In-theatre there was a 30 day currency requirement for dustball landings; however, there was no such requirement for dustball takeoffs or takeoffs requiring either an MPTO or ITO. (1.5.4, 1.5.5)

3.1.20 The investigation determined that the training provided to the FP for operations in dustball/snowball and DVE was insufficient for dealing with the DVE encountered during the accident flight. (1.5.3, 1.5.4, 1.5.5, 2.3.2.1)

3.1.21 The investigation determined that the training for operations in obscuring phenomena provided to CF helicopter pilots, and CH146 aircrew in particular, should be improved. (2.3.2.1)

Findings concerning the Day-HUD, Restraints and ALSE:

3.1.22 The accident crew was not using the Day-HUD; this had been approved by the CO and had become common practice in theatre. (2.2.2, 2.2.4)

3.1.23 The CH146 HUD is not certified as a primary flight instrument. (2.2.3)

3.1.24 The Day-HUD drift vector would have only provided the FP with an additional source of drift information, re-confirming the direction and rate of drift. It is unknown if this would have assisted the FP to recognize, reduce or eliminate the drift. (2.2.4, 2.2.5)

3.1.25 FEs and DGs were using the prototype tactical aviation Crewman Restraint Harness Mk I and some, due to limited availability, did not fit properly or could not be adjusted to a length that would prevent the entire body from projecting beyond the door opening. (1.15.3.4, 2.5.2)

3.1.26 Due to fire damage and the ad hoc distribution and lack of official supply documentation on the prototype CRH/CRTs, the investigation could neither determine if the harnesses were fitted and adjusted properly nor which attachment points were used. (2.5.3)

3.1.27 There was no policy or procedure directing which CRT attachment points FEs and DGs should use during flight. (2.5.3)

3.1.28 The passengers were not securely seated in approved seats with approved lapbelts. (1.15.1.1, 2.5.7)

3.1.29 In this dustball, the FE's ability to see his visual references and, therefore, communicate information concerning drift and obstacles would have been significantly degraded. (2.1.3.4)

Findings concerning the CH146 flight instruments and systems:

3.1.30 As see-through or dust-penetrating technology systems or systems using landing symbology or sensory displays have not yet matured to a level for operational use, none of the CF helicopters, including the CH146, have such systems to conduct safe flight in a DVE below V_{MINI}. (1.6.4.7)

3.1.31 The CH146 helicopter's inherent hover instability, combined with the lack of adequate instrumentation and awareness cues do not allow for safe flight in a DVE below V_{MINI}. (1.6.4.7, 1.18.2.3, 2.6.4)

3.1.32 The CH146 does not have an integrated power display in the cockpit showing a first limit indication or providing situational awareness of the margin remaining to that first limit. (2.9.3.2)

Findings concerning the SMM:

3.1.33 The SMM directed that the FP and the FE inform the crew when they lose visual ground references on approach and landing, however, this direction was not provided for the task VMC Takeoff/Level Off. (1.18.4.3)

3.1.34 The SMM Ch 3 Desert Operations stated that the ITO procedure shall be used during takeoff in obscuring phenomena and that pilots should not attempt the MPTO when a rejection of the take off is likely. Additionally, the SMM suggested that such takeoffs should only be attempted when the aircraft weight is within the limit specified by the HOGE and appropriate wind azimuth charts. (1.18.4.6, 2.6.2)

3.1.35 The investigation found that the intent to conduct the combination of a modified MPTO and transition to an ITO was a logical plan for the crew at the time facing the conditions they faced that day. However, this was not an approved procedure and it would have increased pilot workload conducive to an increased likelihood for a loss of SA. (2.6.2)

3.1.36 The SMM Ch 3 only mentioned a flat pitch attitude for the ITO technique and provided no direction on the desired roll attitude. The direction provided in the ITO section of the SMM, and the crew’s “bar-on-bar” interpretation and application of this technique, created intentional forward drift but also unwanted and unintentional right drift. (2.6.3, 2.6.5, 2.6.6, 2.7.8)

3.1.37 The SMM contained specific details for advising on Qm power setting on takeoff; such detailed calls were not included for ITT limits. (1.18.4.2, 2.9.3.2)

3.1.38 The SMM contains contradictory information concerning the use of the HUD between Task 114 Perform IIMC Procedures, Night Considerations, paragraph 7 and Task 106, Perform VMC Approach/Landing, Desert Operations, paragraph 37. (2.2.3)

Findings concerning the AFM:

3.1.39 The AFM contained discrepancies and errors in the limitations and performance charts that resulted in confusing and inaccurate information regarding aircraft operations and flight planning. (1.16.2.1, Annex G)

3.1.40 The aircraft performance calculation training provided to aircrew contained discrepancies and errors in using AFM charts that resulted in erroneous and inaccurate performance calculations during flight planning. (2.8.5.1)

3.1.41 The investigation revealed that there was no clear understanding of, or clear process for, calculating mission performance data from the AFM or other CH146 operation manuals. (2.8.1.3, 2.8.2.1, 2.8.5.1)

3.1.42 Investigators found confusion within the technical community and a lack of understanding within the operational community concerning the CH146 AFM charts; the requisite knowledge for using the CH146 AFM performance charts was low and posed a high risk for improper and inadequate performance calculations. (2.8.2.1, 2.8.2.2, 2.8.2.3, 2.8.5.1)

3.1.43 Several CH146 aircrew sampled during the investigation used and incorrectly applied the AFM WAT chart ***Figure 1-1A*** (or the similar WAT chart ***Figure 8-13***) as the primary reference for mission planning to determine aircraft performance limitations. Many aircrew were not in the habit of consulting the appropriate charts to calculate aircraft performance and determine if they would have a sufficient power margin to conduct a mission. (2.8.2.3, 2.8.4.1, 2.8.5.2, 2.8.5.5, 2.8.6)

3.1.44 A lack of confidence in the accuracy of the AFM charts within the CH146 aircrew community existed. This led crews to question the validity of the charts, downplay the importance of completing detailed performance calculations and resulted in limited, and at times, inadequate or improper use during flight planning. (2.8.4.1)

Findings concerning ITT:

3.1.45 In Afghanistan from December 2008 to November 2009, CH146 HUMS data recorded 1,120 ITT exceedences in which the ITT was between 810ºC and 940ºC for more than five seconds. (1.11.2.2, 2.9.1)

3.1.46 Aircrew regularly disregarded the 810º-940ºC 5 second transient limit and accepted to regularly exceed published limitations. (2.9.3.1)

3.1.47 HUMS data from the #2 aircraft recorded ITT exceedences greater than 810ºC for longer than 5 seconds on both engines during both the morning and afternoon takeoffs from the FOB. (1.11.2.1, 2.7.11)

3.1.48 ITT exceedences continued to occur without any maintenance, operational or flight safety authorities’ knowledge or oversight. (2.9.2.1)

3.1.49 Investigators found confusion among the aircrew and maintenance communities’ understanding of the differences between operational limitations, maintenance limitations and the potential negative effects on an aircraft component’s service life when these are exceeded. (2.9.2.1, 2.9.3.1, 2.9.4)

Findings concerning performance calculations:

3.1.50 Roto 6 crews had created a performance matrix chart; however, it was neither validated nor approved by the operational or the technical airworthiness authorities. This chart was not used by Roto 7. (1.17.3.2)

3.1.51 It is estimated that the accident aircraft weighed 300 to 500 lbs more than the #2 aircraft. (1.6.6.1)

3.1.52 The ITO procedure required a 23 ft hover capability and therefore OGE performance calculations. The accident aircraft was 460 lbs overweight according to the WAT charts, 1,520 lbs overweight according to the OGE Hover Ceiling Chart available at the time of the accident, and 1,720 lbs overweight according to revised charts provided by AETE. (1.6.6.1, 2.8.6, 2.10.5.1)

3.1.53 The #2 crew attempted and completed the same takeoff as the accident crew; they also lost all references but their application of power was more gradual and they did not pause or limit their application during the takeoff. (2.7.1, 2.7.12)

3.1.54 Both helicopter crews attempted their takeoffs without having checked the appropriate performance charts or verified power margins and they were unaware that insufficient power was available to conduct an OGE takeoff without exceeding ITT limits. (2.8.5.5, 2.8.6, 2.10.6)

3.1.55 Both the accident aircraft and the #2 aircraft were operating in an area of power deficit within the power curve and exceeded ITT limits during their takeoff out of the FOB; they were both in an overweight condition. Neither had power available to attempt an OGE takeoff given their estimated AUW. (2.10.2.2, 2.10.4.2, 2.10.5.2, 2.10.6)

3.1.56 A review of the CH146 operating manuals found little guidance or criteria on how to use performance calculations to support mission acceptance or substantiate mission rejection but RCAF flying regulations provide ACs the required authority to accept or reject missions that can accomplished. (2.10.5.2)

3.1.57 A review of the CH146 SOI found that given the environmental conditions of the day, the accident aircraft was capable of IGE hover but not capable of OGE hover. The investigation also found that the long-term solution to increase the HD envelope for AUW operations found in the CH146 SOI had not been resolved. (1.17.2.1, 2.11.3.1)

Findings concerning the CF and RCAF:

3.1.58 AETE reports concluded that BHTC testing did not include any testing germane to the specific requirements of its intended military missions, therefore, the suitability of the CH146 as a utility tactical transport helicopter in support of land forces or as a combat support helicopter could not be assessed. (2.8.1.1)

3.1.59 Performance charts unique to the CH146 were never independently validated by AETE; the CF accepted the civil Bell Model 412 charts as the CH146 Griffon performance charts. (2.8.1.2)

3.1.60 The CH146 deployment decision briefings focussed mainly on the range and payload capacity; the limited CH146 performance data that was presented was based solely on the ***Figure 8-11*** WAT chart. (2.11.1.2)

3.1.61 Despite the challenges of operating at high OAT and density altitudes, the Griffon was suitable and very effectively employed within operational limits for operations in Afghanistan for certain specific missions. (2.11.1.2)

3.1.62 The RCAF chain of command, including operational and technical authorities, had the full expectation that the helicopters would be flown within limitations detailed in the aircraft flight manuals. (1.17.1.2, 2.11.1.1)

3.1.63 To mitigate the CH146 performance in the high, hot and heavy regimes and the limited on board self-defence/survivability equipment issues, specific operational parameters were offered. However no strategic level documents were found directing the tactical level in Afghanistan to implement these measures; the investigation revealed a breakdown in communication between the commander’s strategic level intent to mitigate the CH146 performance in the high, hot and heavy regimes and the day to day operations at the tactical level. (2.11.1.6)

3.1.64 Investigators found several factors that contributed to hamper the amount of support provided from higher headquarters. Specifically the limited number of personnel in key technical, operational and strategic level headquarters contributed to inadequate oversight and planning support from higher headquarters during the preparation and planning phases of the CH146 deployment to Afghanistan. (2.11.2.1, 2.11.2.2, 2.11.2.6, 2.11.4)

3.1.65 The investigation found that the MA-LA process did not support or lead to a proper assessment of the climatic conditions and, hence, aircraft performance for that specific mission at the FOB that day. (2.1.3.5)

3.2 Cause Factors

Active Cause Factors

3.2.1 The intense dustball contributed to a DVE that removed the crew’s visual ground references and the FP’s ability to see and avoid the barrier.

3.2.2 The CH146 inherent hover instability and lack of adequate instrumentation and awareness cues when operating in instrument conditions or in a DVE below V_{MINI} contributed to forward and unintentional right drift.

3.2.3 During the takeoff, while by cross-checking the ITT gauge, the FP lost visual references.

3.2.4 The FP suffered a loss of situation awareness due to the rapid and numerous changes in his focus during the takeoff.

3.2.5 During the takeoff, while cross-checking the ITT gauge, the FP reduced power, which reduced the helicopter’s climb momentum, and inadvertently made a right cyclic input which exacerbated the right drift.

3.2.6 The bar-on-bar or flat pitch attitude technique described in the SMM ITO exacerbated forward and unintentional right drift.

3.2.7 The accident aircraft AUW exceeded aircraft limits given the environmental conditions.

Latent Cause Factors

3.2.8 The crew used a non-standard procedure by combining an MPTO and ITO. Although a logical plan for them at the time, it was contrary to the procedures in the SMM, increased pilot workload and the chances for loss of situation awareness.

3.2.9 The training received by the FP for operations in DVE or obscuring phenomena was inadequate.

3.2.10 The crew attempted to conduct a takeoff not knowing that the aircraft had an insufficient power margin to remain within engine ITT limitations.

3.2.11 Power and performance calculations were not completed for the FOB takeoff; the crew did not realize the substantial performance limitations and did not expect or anticipate having to complete performance calculations for this particular takeoff given the AUW and environmental conditions.

3.2.12 Several aircrew within the CH146 community incorrectly applied the WAT charts as the primary reference for mission planning.

3.2.13 A lack understanding and lack of confidence in the accuracy of the AFM performance charts led CH146 aircrew to question the validity of the charts and downplay the importance of completing detailed performance calculations.

3.2.14 Errors and omissions in critical operational and technical reference material precluded the crew from accurately conducting essential pre-flight calculations had they attempted to do so. Insufficient information was available to CH146 aircrew to properly explain or describe the use of the performance charts or how to determine actual power margins.

3.2.15 The CH146 was approved for use in Op ATHENA for a variety of missions without the direction, development and implementation of proper mitigation strategies for certain missions.

3.2.16 There was a breakdown in communication between the commander’s strategic level intent to mitigate the CH146 performance in the high, hot and heavy regimes and the day to day operations at the tactical level.

3.2.17 The limited number of personnel in key technical, operational and strategic level headquarters contributed to inadequate oversight and planning support from higher headquarters during the preparation and planning phases of the CH146 deployment to Afghanistan.

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4 PREVENTIVE MEASURES

4.1 Preventive Measures Taken

4.1.1 The TAA and OAA conducted risk identification and management activities through the RARM process on several CH146 performance issues, including OAT limitations, performance chart discrepancies, AUW adjustment factors and OGE Hover GW. The applicable CH146 RARMs are listed in the footnote below.[50]

4.1.2 The TAA conducted a review of the CH146 AFM. Many of the AFM performance charts have been, or are in the process of being replaced with new charts that accurately depict aircraft performance and limitations. The *FLIGHT MANUAL SUPPLEMENT, CH146 GRIFFON, OPERATION WITH NINE PASSENGERS OR LESS (ENGLISH*) was released on 13 Oct 09. The current version was released on 18 Nov 09 and was then transferred into the Integrated Electronic Technical Manual (IETM)[51] on 09 Jul 10. The long-term goal is to review the entire AFM for accuracy, applicability and ease of use. With respect to Hover Ceiling charts, the CH146 WSM is working to finalize new Min Spec charts for both IGE and OGE.

4.1.3 The TAA processes have been changed since the release of AFM Ch 2, which will prevent any change to the AFM without appropriate review by TAA and OAA staff. This should prevent both the introduction of unauthorized charts and their use to predict performance and limitations.

4.1.4 The DAEPM(TH) staff developed software and procedures capable of accurately predicting power required and available for takeoff. These were in use in Afghanistan until the end of the mission. Due to certification, implementation and increased maintenance challenges in supporting the PPI software, a variation of this software for domestic operations will not be pursued.

4.1.5 The Crewman Restraint Harness MK II with the Crewman Restraint Release has been fully fielded and is now available in all sizes and sufficient

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[50] The applicable RARMs listed by serial number and title include:

a) CH146-2010-010: CH146 Flight Manual Hover Performance Chart Discrepancies
b) CH146-2009-020: CH146 AUW Adjustment Factors Based on Actual Engine Performance
c) CH146-2009-019: CH146 Enhanced Maximum OGE Hover Gross Weight with Effect of Skid Height Above Ground
d) CH146-2009-016: CH146 Roll Limit Exceedences – Deployed Operations
e) CH146-2009-015: CH146 Flight Manual WAT/Performance Chart Discrepancies
f) CH146-2009-014: CH146 Expansion of VNE Limitations – Deployed Operations
g) CH146-2009-012: Deployed Operations Beyond CH146 Outside Air Temperature Limitations
h) CH146-2009-008: CH146 Cumulative Effect of VNE Exceedences – Deployed Operations
i) CH146-2009-003: CH146 Fatigue Life Calculations for Deployed Operations – OP Athena
j) CH146-2008-003: CH146 Operations with Doors Opened and Pinned
k) CH146-2008-001: CH146 Combat Configuration for Afghanistan

[51] Integrated Electronic Technical Manual (IETM) is the electronic database storing all CH146 technical publications.

quantities. The CRH Mk 1 is no longer in service. The OEM for the CRH MK II CRR has been tasked to develop of a shorter version of the CRR for use on the specific CH146 Gun configuration with the CRH MK II.

4.1.6 1 Cdn Air Div released several messages concerning CH146 publication amendments, performance planning calculations and mitigation plans. They are listed in the footnote below. [52]

4.1.7 Additional post-accident activities included publishing SMM Change 4 and Change 5 as well as an entire re-issue of the SMM on 31 May 2011. Amendments directly related to this accident include changes to the following Chapters and Tasks:

a. Chapter 1 CREW COORDINATION:

i. The paragraph HEADS-UP DISPLAY (HUD) SYSTEMS was added providing guidance on the use of the Day and NVG HUD/HMD for use in various operating environments.

ii. The paragraph ADI SETTINGS was added providing guidance on the use of the ADI.

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[52] 1 Cdn Air Div messages include:

a) UNCLAS A3 APT 057, Mitigation Plan - CH146 OGE Charts - Amendment 1
b) UNCLAS A3 APT 047, Immediate Mitigation Plan - CH146 OGE Charts
c) UNCLAS COMD 1157, POAC CH146 – OP Athena Performance Planning – Rev 1
d) UNCLAS COMD 1124, CH146 POAC – OP Athena Performance Planning
e) UNCLAS COMD 625, CH146 POAC – OP Athena Performance Planning
f) UNCLAS COMD 1203, OA Appr - B-GA-002-146/FP-001 Change 0 CH146 SMM
g) UNCLAS COMD 594, OA Appr: C-12-146-000/MB-Z60 CH146 AOI Supplement
h) UNCLAS COMD 628, Publication Amendment: CH146 Flight Manual
i) UNCLAS COMD 621, OA Approval B-GA-002-146/FP-001 Change 5 CH146 SMM
j) UNCLAS COMD 620, OA Approval C-12-146-000/MB-Z60 CH146 AOI Supplement
k) UNCLAS COMD 1334, CH146 POAC: Rotor Track and Balance Regime – Hot and High
l) UNCLAS COMD 1024, POAC CH146B Deployed Operations Configuration Rev 1
m) UNCLAS COMD 565, CH146 POAC: Op Athena Increased VNE Limits
n) UNCLAS COMD 556, CH146 POAC: Op Athena Increased VNE Limits
o) UNCLAS COMD 559, POAC: CH146 Deployed Ops Above Published AOI OAT Limits
p) UNCLAS COMD 077, Comd Auth CH146 Deployed Ops Above OAT Limit
q) UNCLAS APT RDNS 034, CH146 VNE Exceedences
r) UNCLAS APT RDNS 044, CH146 Doors Open Operational Restriction
s) UNCLAS COMD 1061, POAC CH146B Deployed Operations Configuration
t) UNCLAS COMD 616, POAC CH146B Deployed Operations Configuration
u) UNCLAS COMD 652, POAC CH146B Deployed Operations Configuration
v) UNCLAS COMD 154, Commander's Authorization for Use – CH146 Combat Configuration
w) UNCLAS COMD 524, Use of IR Anticolliders on CH146

iii. Chapter 2 AIRCREW TASKS, Task 100 CALCULATE AIRCRAFT WEIGHT AND BALANCE: The paragraph Environmental Considerations was amended to introduce considerations for operations at higher altitudes and warmer temperatures. This includes discussion on performance limitations (weight, Qm, ITT or N1), power available, power required, go/no-go criteria and the requirement to monitor aircraft operation and performance throughout the flight.

b. Chapter 2, Task 101 PREPARE A PERFORMANCE PLANNING CARD: This task saw multiple changes to improve pre-flight calculations including:

i. The mission planning procedure for calculating power and performance numbers for both IGE and OGE (power available and power required);

ii. The calculation of maximum aircraft weight allowable at all planned landing locations for the mission;

iii. A flow chart to identify the charts to be followed to calculate maximum AUW from the various performance charts contained in the CH146 Flight Manual;

iv. Sample performance calculations; and

v. Modifications to the CH146 Performance Planning Card to include power available and power required IGE and OGE as well as performance information for intermediate landings during the mission.

c. Chapter 2, Task 105 PERFORM VMC TAKE-OFF / LEVEL-OFF, was amended with several procedural changes to improve the MPTO and the ITO:

i. The MPTO procedure was amended with changes to pre-flight preparations, the requirement or feasibility of the hover check, power and performance considerations (i.e. Qm, N1 and ITT limitations), operations in DVE considering obstacle clearance and confined areas, abort procedures and specific crew duties;

ii. The ITO procedure clarified the technique, the use of the ADI, the use of the drift vector from the HUD/HMD and included a Caution on the use of the ITO in confined areas or near obstacles. The Caution also highlighted the presence of right drift in a wings-level attitude; and

iii. A 5% power margin was incorporated into the SMM to account for additional power required for transition to forward flight. This was also built into the performance calculator software developed by the WSM staff.

d. Chapter 2, Task 106 PERFORM VMC APPROACH / LANDING was modified and consolidated information for operations in DVE under sections entitled OBSCURING PHENOMENA and DESERT OPERATIONS.

e. Chapter 2, Task 109 PERFORM CONFINED AREA (CA) OPERATIONS was amended to include crew management duties for Tactical Aviation aircrew.

4.1.8 1 Cdn Air Div Orders, Volume 2, 2-007, was amended to mandate that all passengers be seated in an approved seat and secured with an approved lap belt for all takeoffs and landings.

4.1.9 1 Wing Tactical Aviation Standards and Evaluation Team (TASET) included a 10-part question in the CH146 Pilot Annual Category Open Book Examination to address AFM performance planning and chart utilization. Standards personnel correct the examinations to 100%.

4.1.10 Directorate Air Requirements (DAR) 9 has been tracking DVE solutions before OP ATHENA and after two Flight Safety Investigations which had issues with DVE. DAR 9 assesses that the solution (as explained in paragraphs 1.6.4) for DVE operations encompasses three elements: improved handling qualities, see-through sensors, and symbology. The improved handling quality requirements call for a 4-5 axis stabilization systems mostly available on advanced helicopter platforms only. With the CH146 Griffon as a 2.5 axis platform, improvements to handling qualities would require significant modifications to the flight control and navigation systems to the extent of a full mid-life upgrade. It is highly likely that such an extensive modification program would not be entertained as a replacement by a modern platform would most likely be a more fiscally and prudent course of action. The area of see-through sensors is still considered at the developmental and experimental stages. Developmental work is being carried out by DRDC on symbology and the results could be considered for implementation on existing rotary wing fleets within five yrs.

4.1.11 Under the Degraded Visual Environment Solution for TacHel (DVEST) technology demonstration program, DRDC funded a trial on a number of HMD brown-out symbology systems to enhance crew efficiency in DVE. Two leading-edge symbology systems for takeoffs, landings, approaches and hovering flight under DVEST will be assessed; the evaluation also concentrates on the human factor elements inherent in these symbology systems. DRDC is in the process of setting a contract through Public Works and Government Services Canada (PWGSC) once a specific symbology system is chosen. It is expected the contract will be awarded in 2012 with a simulator evaluation, a flight test and recommendations to DAR 9 before end-2013. Finally, DRDC is concurrently working on a form of dust penetration laser radar so that it might be combined with the symbology system.

4.2 Preventive Measures Recommended

4.2.1 The OAA/1 Cdn Air Div/A3 Tac Avn, with support from TASET and the TAA/DAEPM(TH), should amend the CH146 AFM with validated and accurate CH146 performance charts.

4.2.2 The OAA/1 Cdn Air Div/A3 Tac Avn, with support from TASET and the TAA/DAEPM(TH), should amend the CH146 AFM, and the SMM if required, with clear direction on the correct use of the CH146 performance charts.

4.2.3 The OAA/1 Cdn Air Div/A3 Tac Avn, with support from TASET and the TAA/DAEPM(TH), should amend the CH146 AFM to develop clear unambiguous wording for AFM ITT limits.

4.2.4 The OAA/1 Cdn Air Div/A3 Tac Avn/TASET should address the CH146 aircrew training and knowledge concerning performance calculations provided at 403 HOTS. Training should provide clear direction on the use of performance charts for proper and accurate calculations in various operating and environmental conditions, including scenarios for high altitudes, OATs and AUWs.

4.2.5 The OAA/1 Cdn Air Div/A3 Tac Avn/TASET should address the CH146 training and knowledge concerning tail rotor couple and right drift during the ITO procedure. The procedure should be reviewed to consider a vertical departure based on a hover attitude that would not induce drift.

4.2.6 The OAA/1 Cdn Air Div/A3 Tac Avn/TASET should improve the training for operations in obscuring phenomena provided to CF helicopter pilots, and 1 Wing aircrew in particular.

4.2.7 The OAA/1 Cdn Air Div/A3 Tac Avn/TASET should further amend the SMM to include:

a. Monitoring and calling ITT limits during takeoffs;

b. Providing an Abort procedure for an ITO;

c. Providing direction on specific safety distances required for obstacle clearance and during confined area operations when considering an ITO;

d. Providing direction on crew advisory calls when losing references during critical phases of flight; and

e. Correcting the contradictory statements in the SMM concerning use of the HUD between Task 114 Perform IIMC Procedures, Night Considerations, paragraph 7 and Task 106, Perform VMC Approach/Landing, Desert Operations, paragraph 37.

4.2.8 The OAA/1 Cdn Air Div/A3 Tac Avn/TASET should include dustball takeoff techniques, including an MPTO and ITO, in CH146 initial training and as ongoing currency requirements during exercises or operations (domestic or deployed abroad) where the potential for DVE exists.

4.2.9 The TAA/DAEPM(TH) should continue the development of performance software planning tools or quick reference performance matrix charts for the CH146 operations in high HD, high OAT and high AUW conditions for both domestic and deployed operations abroad.

4.2.10 The TAA/DAEPM(TH) should modify the Day-HUD symbology display illumination levels to ensure effective use of the Day-HUD in various operating environments.

4.2.11 The AA/DAR should continue its research into current technologies regarding brownout or dustball symbology systems to improve operations in the DVE and provide the C Air Force with recommended systems for acquisition and use by CF helicopters.

4.2.12 The AA/DAR 9 should consider an upgrade to the symbology of the CH146 HUD from the current 2 Dimensional (2-D) set to an advanced 3-D symbology set.

4.2.13 The AA/DAR 9 should include improved handling qualities to allow for auto-hover capability and see-through sensors as requirements for the Griffon replacement.

4.2.14 The AA/DAR 9 should consider an upgrade to the cockpit for an integrated power display showing a first limit indication of torque and ITT. This could provide situational awareness of the power margin remaining to the first limit.

4.2.15 Canadian Joint Operations Command (CJOC) [formerly known as CEFCOM]/1 Cdn Air Div should implement criteria and minimum standards for Crash Fire Rescue response and dust suppression for Main Operating Bases, FOBs and landing zones during internationally deployed operations. These criteria should be clearly communicated to Canadian and Allied Forces at the onset of future missions and should be added to future MA-LA risk factors so that the Chain of Command could have visibility of the risk in advance of accepting particular missions.

4.2.16 DRDC should consider and evaluate other potential options for displays, sensors, and flight controls for helicopter operations in DVE by various groups in the broader international aviation industry.

4.2.17 The AA should consider the creation of capability planning teams for major deployments. These would include technical, tactical, operational, and strategic level SMEs to conduct comprehensive expert assessments of RCAF capabilities to identify and address issues when deploying forces. The intent is also to ensure the commander's strategic level intent is effectively communicated down to the tactical level.

4.3 Other Safety Concerns

4.3.1 This and other occurrences have highlighted to DFS and TAA staff that CF rotorcraft are often not operated according to certification assumptions, i.e., different takeoff or landing procedures and flight profiles are used. The performance data in the AFM is valid only for specific procedures; if other procedures are used, the AFM data can be inaccurate or misleading and data that would be applicable is not available. Flight profiles used for the AFM data often provide safety margins for specific events; altering these profiles can eliminate these safety margins which lead to an elevated risk that must be weighed against the operational context. The intent of the following safety recommendations is twofold: first, to review aircraft performance data to ensure it is applicable to CF operations and second, to avoid new certification programs where AFMs could be developed with data that would not be used in the CF operational context and/or without the data that should be. If such gaps exist the OAA and the TAA should obtain and provide the applicable data to ensure safe and effective operations can be conducted.

4.3.2 Given that the CT146 Outlaw is a civil registered aircraft and not managed by DGAEPM, the TAA should engage PWGSC/Transport Canada to approach BHTCL to review the validity of the applicable performance charts for the CT146 Outlaw.

4.3.3 The AA should ensure that performance deficiencies associated with adapting civilian aircraft models for CF use, such as differences between certification assumptions/standards and CF operational procedures, are considered and rectified for the CH146 Griffon. This should also be completed for future CF aircraft acquisitions, such as the CH148 Cyclone, the CH147F Chinook and other replacement projects.

4.4 DFS Comments

First and foremost, I would like to acknowledge the individuals who made the ultimate sacrifice for their country while struggling to bring peace and stability to Afghanistan. Two Canadians and one coalition military member from the United Kingdom perished in this tragic accident.

The decision to deploy the CH146 to Afghanistan was not taken lightly as the capabilities and risks were evaluated, assessed, and ultimately accepted by the Chain of Command. Back in the 2006-08 timeframe, the number of Canadian casualties in Afghanistan was increasing at a rate that Canada had not seen since the Korean conflict. The deployment of the Air Wing, including the CH146, provided crucial support for our ground forces and the missions flown by our crews ultimately saved lives; however, that is not to say that we, as an organization, deployed the CH146 without error.

CH146434’s accident highlighted some weaknesses and gaps in our operating procedures and with our capabilities, such as aircraft and aircrew equipment, flight training, and procedures for helicopter operations in obscuring phenomena. Significantly, both the technical and operational authorities had an incomplete understanding of aircraft performance charts that were somewhat confusing and not operator friendly. The result was that CH146 crews conducted missions in the Afghan theatre using wrong charts while dismissing correct ones.

Of even more concern was the lack of feedback from those operational experiences interfacing with the Airworthiness Process. During operations, personnel are empowered to make decisions in order to carry out their assigned missions to the best of their abilities given their training, the equipment with which they deploy, and the situations they face. However, when problems are encountered during mission execution, operators must interface with Airworthiness Authorities so that assessments of the problems can occur. In this case, the constant over-temps and over-torques over many months should have been reported to the appropriate Airworthiness Authorities. Because this feedback into the Airworthiness Process did not occur, the Airworthiness Authorities could not validate the mission planning and execution, offer mitigation strategies, direct alternate mission profiles or understand and plan for the consequences of accelerated equipment wear. As the Airworthiness Investigative Authority I find this worrisome and a problem that must be addressed so that our Airworthiness Processes emerge stronger and better prepared to operate in conflict operations.

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To conclude, my comments are not meant to diminish the outstanding professionalism, devotion and heroism of our personnel who conducted essential missions under the most demanding circumstances. Rather, they are intended to submit that as a planning and risk assessment tool, the operational staffs need to work closely with the Flight Safety Team to ensure effective mission accomplishment within a combat environment.

Yvan Choiniere
Colonel
Director Flight Safety

Annex A: Photographs

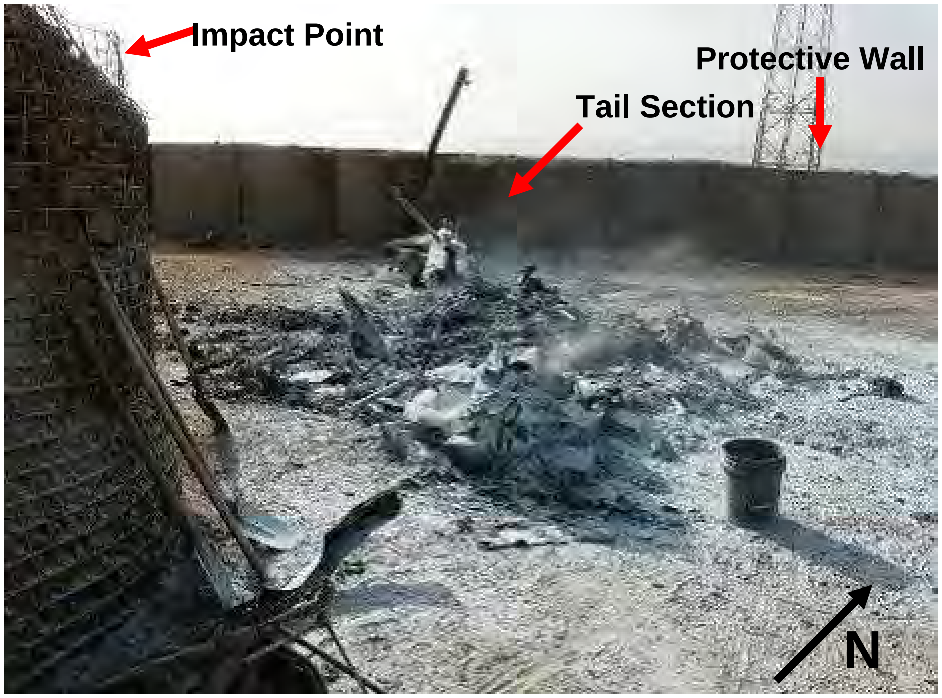

Photo 1: Accident site from impact point

Photo 2: Damaged barrier showing side of aircraft impact

Photo 3: Damaged barrier showing main rotor blade strike


Photo 4: CVFDR as received at NRC

Photo 5: Accident site after the evacuation of survivors

Photo 6: Accident site looking from the protective wall

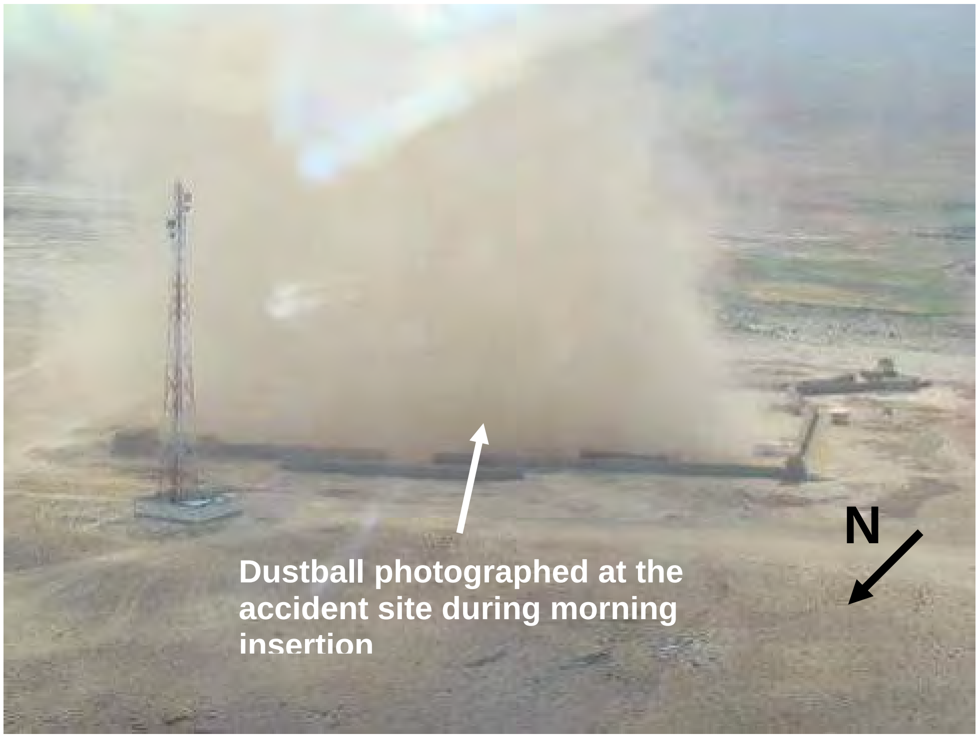

Photo 7: A dustball at the accident site as viewed from the air

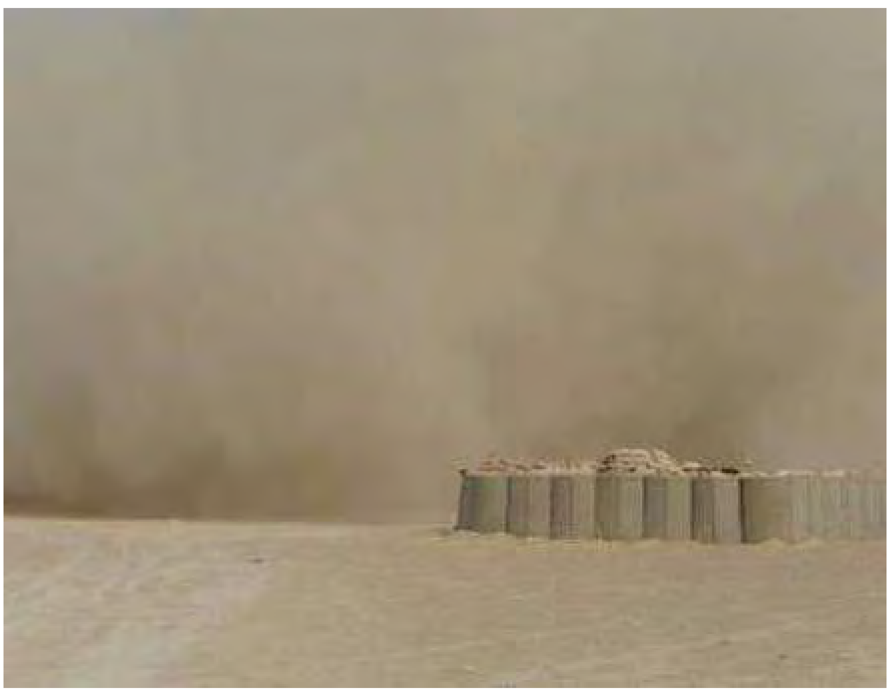

Photo 8: A dustball at the accident site as viewed from the ground

Photo 9: Transmission side-facing seat, FE side (investigator seated, photo used with permission)

Annex B: Aircraft Performance Definitions

To facilitate the understanding of aircraft performance, definitions relevant to this accident are listed here:

a. Brownout: A condition during taking off or landing in an arid climate where there is little or no out-the-cockpit window visibility caused by dirt and dust being stirred up by the rotor downwash and then re-circulated by the rotor blades of a helicopter. Similar conditions can be created by landing or taking off in snow (whiteout) or over water. It should be noted that whiteout in snowy conditions is also commonly referred to as "snowball" by aircrew to distinguish this particular condition from atmospheric whiteout caused by omnidirectional cirrus cloud formation, fog, or overcast sky over continuous snow surface or intermittent cloud blend in with snow-covered terrain. In general, DVE cause pilots to rely on inadequate cockpit instrumentation, callouts by on-board aircrew, and innate piloting skill to successfully execute a brownout landing. Flying in DVE has always been a challenge for rotary-wing pilots. Since NATO has been operating in the arid climates (e.g., Africa and Afghanistan), Rotary-Wing Brownout (RWB) is responsible for approximately 75% of coalition helicopter mishaps.[53]

b. In Ground Effect (IGE)/Out of Ground Effect (OGE): When a helicopter is hovering in close proximity to the ground (one rotor diameter or less), it is said to be hovering IGE. Because of the close proximity to the ground, the downward and outward airflow pattern tends to restrict vortex generation. This makes the outboard portion of the rotor blade more efficient and reduces overall system turbulence caused by ingestion and recirculation of the vortex swirls. Therefore, for the same collective (power) setting, more weight can be lifted IGE than OGE.[54]

c. Minimum Specification (Min Spec): Aircraft performance information in the AFM is predicated on Min Spec engines. Aircraft engines performing at Min Spec or above meet the certification requirements and are considered serviceable. Engines performing below Min Spec are considered unserviceable and require maintenance action before returning to service.

d. Power Assurance Check (PAC): The PAC is used to determine if the installed engines can produce Min Spec power. CH146 aircrew were to conduct a PAC on the first flight of each flying day to determine if the engines were serviceable. The PAC compares an ITT value on a checked engine to the calculated value of a Min Spec engine. For a given Qm, pressure altitude (HP) and outside air temperature (OAT), a serviceable engine will have an ITT value at or below the calculated or chart derived ITT value. The PAC, however, does

[53] North Atlantic Treaty Organisation, Research and Technology Organisation, (January 2012), RTO Technical Report TR-HFM-162, ***Rotary-Wing Brownout Mitigation: Technologies and Training***.
[54] As defined in Manual of Aerodynamics, A-12-050-001/PT-001.

not indicate, determine or calculate the actual power margin available. The majority of CH146 aircraft perform better than Min Spec.

e. Power Required[55]: In the calculation of power required, one must understand the importance of total drag curves. On a drag/velocity diagram, the total drag curve represents the combination of induced, parasite and profile drag[56], as in Figure 1. At low velocities, the drag curve starts at a relatively high point, decreases as speed increases to reach the optimum lift over drag ratio (the low point in the curve) and then increases as speed increases. The power required to maintain steady un-accelerated, level flight is equal to the total drag. As such, the total drag curve may also be referred to as the power required curve. Power required at low speed, or in the hover is relatively high. It will decrease as speed reaches the optimum lift over drag speed and then increase as speed increases in forward flight.

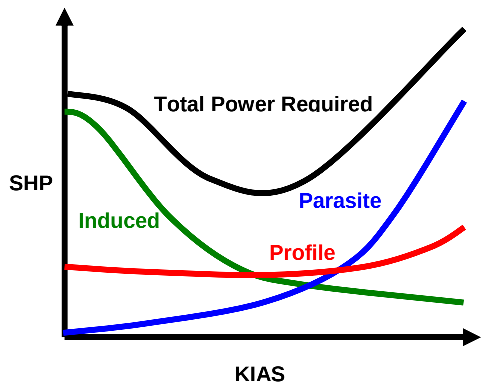

Figure 1 – Power Required Curve[57]

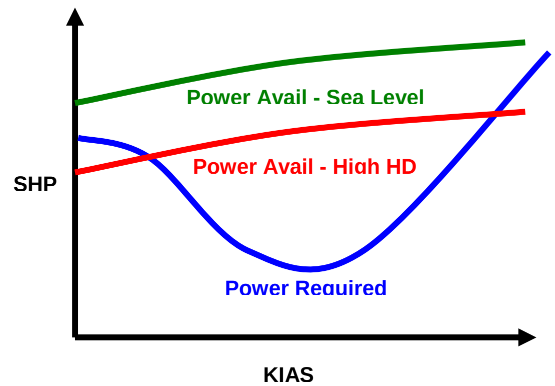

Figure 2 - Power Available Curve[58]

f. Power Available: To determine aircraft performance characteristics, power available must also be considered. Helicopters demonstrate roughly the same power available in a hover as they do at their maximum airspeed, it is the power required that varies in the different flight conditions between the hover and forward flight. Therefore on a drag/velocity diagram Figure 2, the maximum power available is depicted as a relatively flat curve that rises slightly as airspeed increases above the lift/drag/power required curve. Power available is the maximum power that can be produced by the aircraft (combining total engine

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55 Major David P. Lobik, *Power Available vs Power Required - the saga continues…,* With permission from the School of Aviation Safety, Pensacola Fl, Rotary Wing Aerodynamics Instructor.

56 R.W. Prouty, *Helicopter Aerodynamics Volume 1, 2009* Eagle Eye Solutions, LLC. Induced power is that associated with producing rotor thrust. Profile power is used to overcome friction drag on the blades. Parasite power is that needed to overcome the drag of all the aircraft components except rotor blades.

57 The diagrams in Figures 1, 2 and 3 are consolidated graphs taken from Lobnik, *Power Available vs Power Required - the saga continues….*and modified with information taken from Prouty, *Helicopter Aerodynamics Volume 1.*

58 Ibid.

power with other demands from systems such as rotor systems, main and tail rotor drive gearbox losses, hydraulic pumps, generators, etc) and is affected by factors such as temperature, HD and GW. As temperatures, altitudes, HD and GW increases, most engines cannot provide all of the horsepower demanded by the transmission and other aircraft components; therefore, the aircraft power available line will shift downward.[59]

g. Power Margin: A power margin is that differential between the power available and the power required.

h. Power Deficit: The deficiency or lack of power that is depicted by that area where the power required curve is above the power available curve. In Figure 3, it is depicted at those speeds below V_{MINI} and above V_{MAX} (shaded area), as would be the case in a high (high altitudes or high HD), hot (high OAT) and heavy (high GW) flight regime.

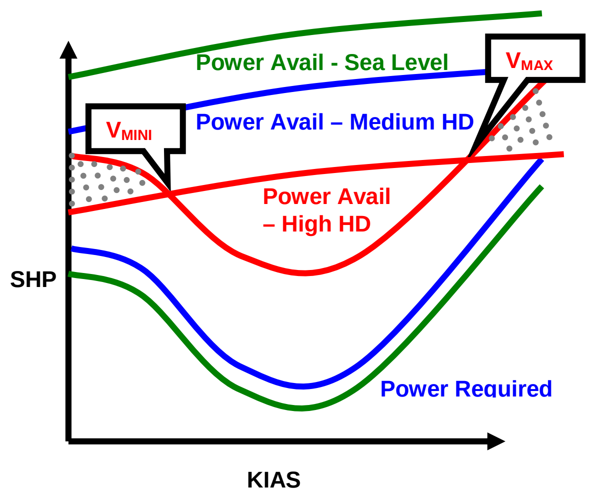

Figure 3 - Power Deficit (At speeds in the shaded areas slower than V_{MINI} and faster than V_{MAX}. The Sea Level, Medium and High HD lines are provided as examples.)

i. Power/Mast Torque Limited: In addition to Qm, CH146 performance can be limited by, among other parameters, ITT and gas producer RPM (N1). When an aircraft is described as power-limited, sufficient Qm is available but ITT or N1 limits would be reached first. Conversely, an aircraft is Qm limited when Qm would be met prior to reaching ITT or N1 limits.

---

[59] D.P. Lobik. As jet engines need to balance a proper fuel-to-air ratio to ensure maximum efficiency at all torque settings, when the air gets thinner as it will with an increase in DA, then the fuel introduced by the fuel management systems becomes less thus limiting the power available. This is because jet engines operate most efficiently when the fuel-to-air ratio is held constant for combustion.

Annex C: Weight, Altitude, Temperature (WAT) and Hover Ceiling Charts

Figure 1-1: WAT Chart – IGE

Note: Notice the note referring to the Hover Ceiling charts and the Limit Line to guarantee Min Spec performance.

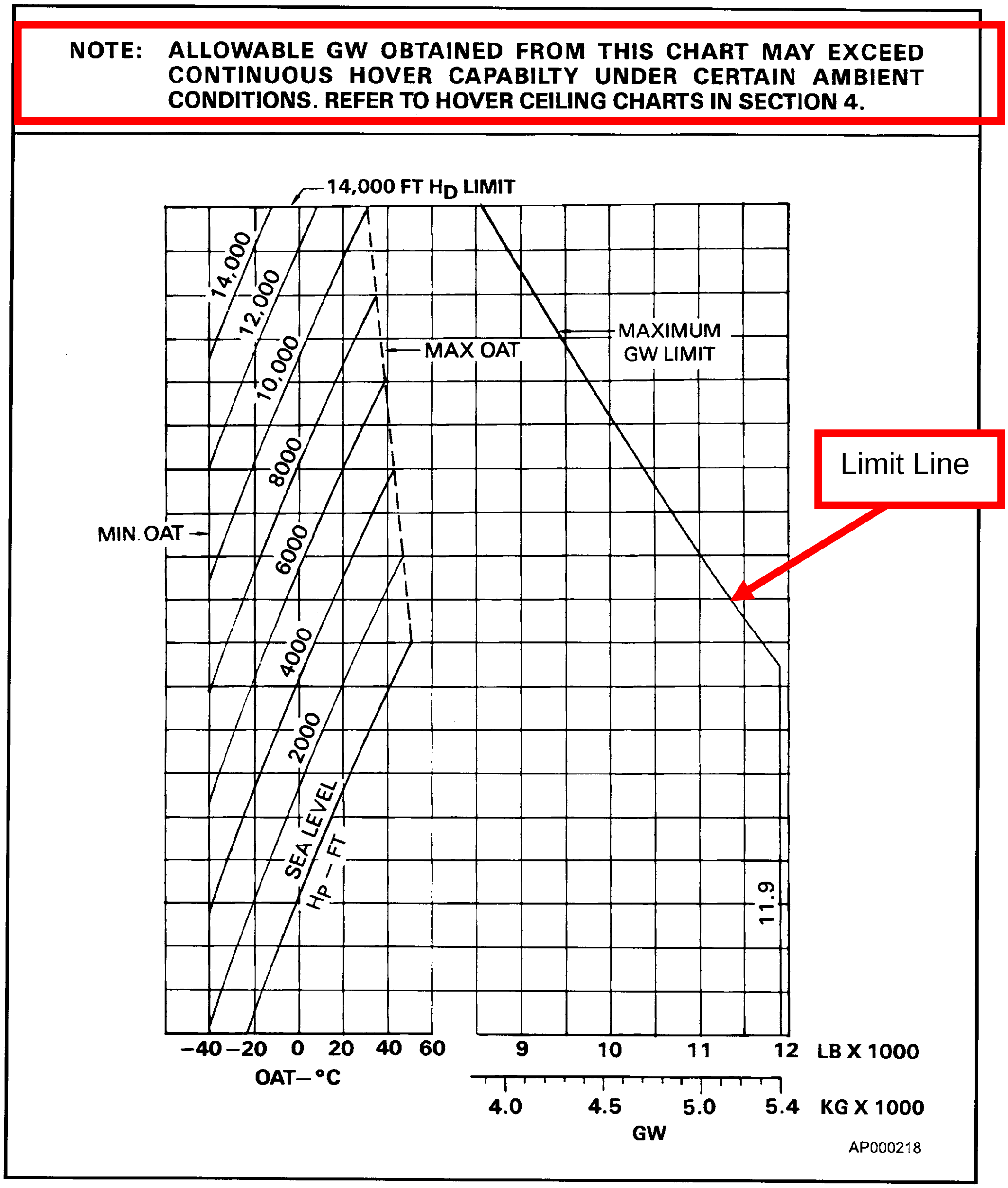

Figure 1-1. Weight-altitude-temperature limitations for takeoff, landing, and in-ground-effect maneuvers, all wind azimuths, 10 passenger or more

Source: C-12-146-000/MB-002

Figure 1-1A: WAT Chart – IGE

Note: KAF takeoff in red, FOB takeoff FOB in blue. Notice the lack of a note to refer to Hover Ceiling charts and lack of a Limit Line to guarantee Min Spec performance. This chart has since been removed.

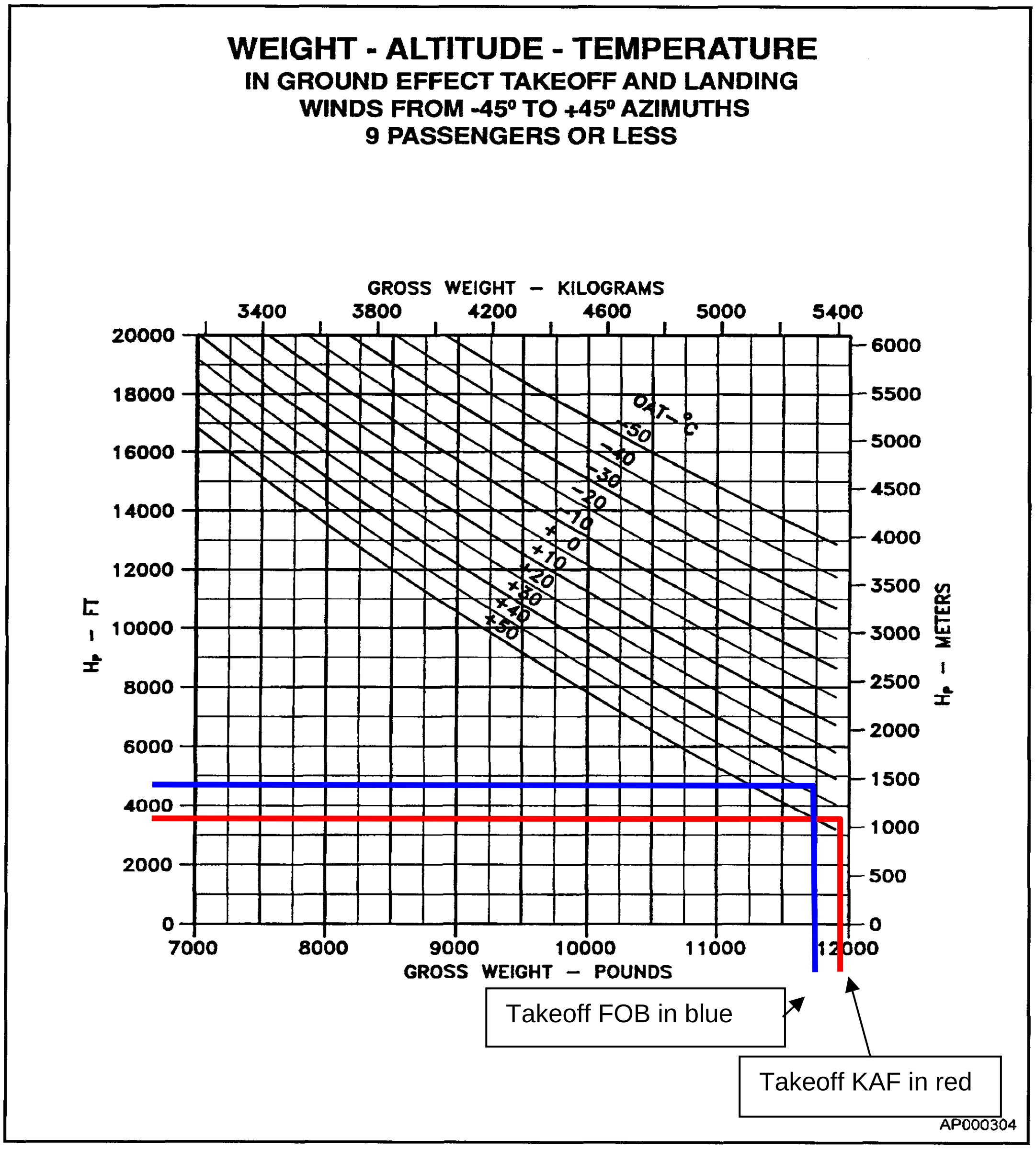

Figure 1-1A. Weight-altitude-temperature limitations for takeoff, landing, and in-ground-effect maneuvers, wind from -45° to +45° azimuths, 9 passenger or less

Source: C-12-146-000/MB-002

Figure 8-12: WAT Chart – OGE

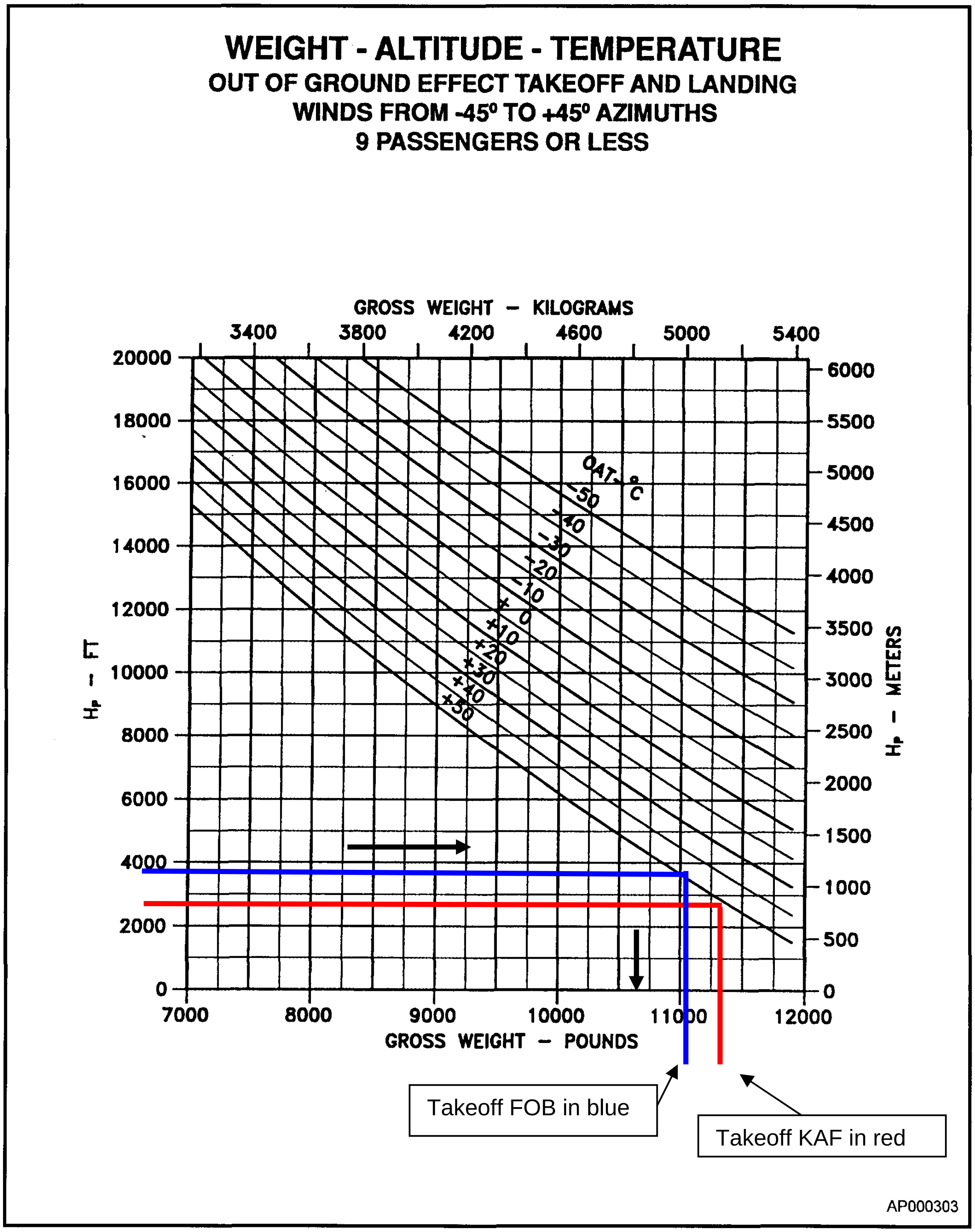

Figure 8-12. WAT chart, OGE, 9 passengers or less

Source: C-12-146-000/MB-002

Figure 8-11: WAT Chart – OGE

Note: This chart was used for CH146 deployment decision briefings.

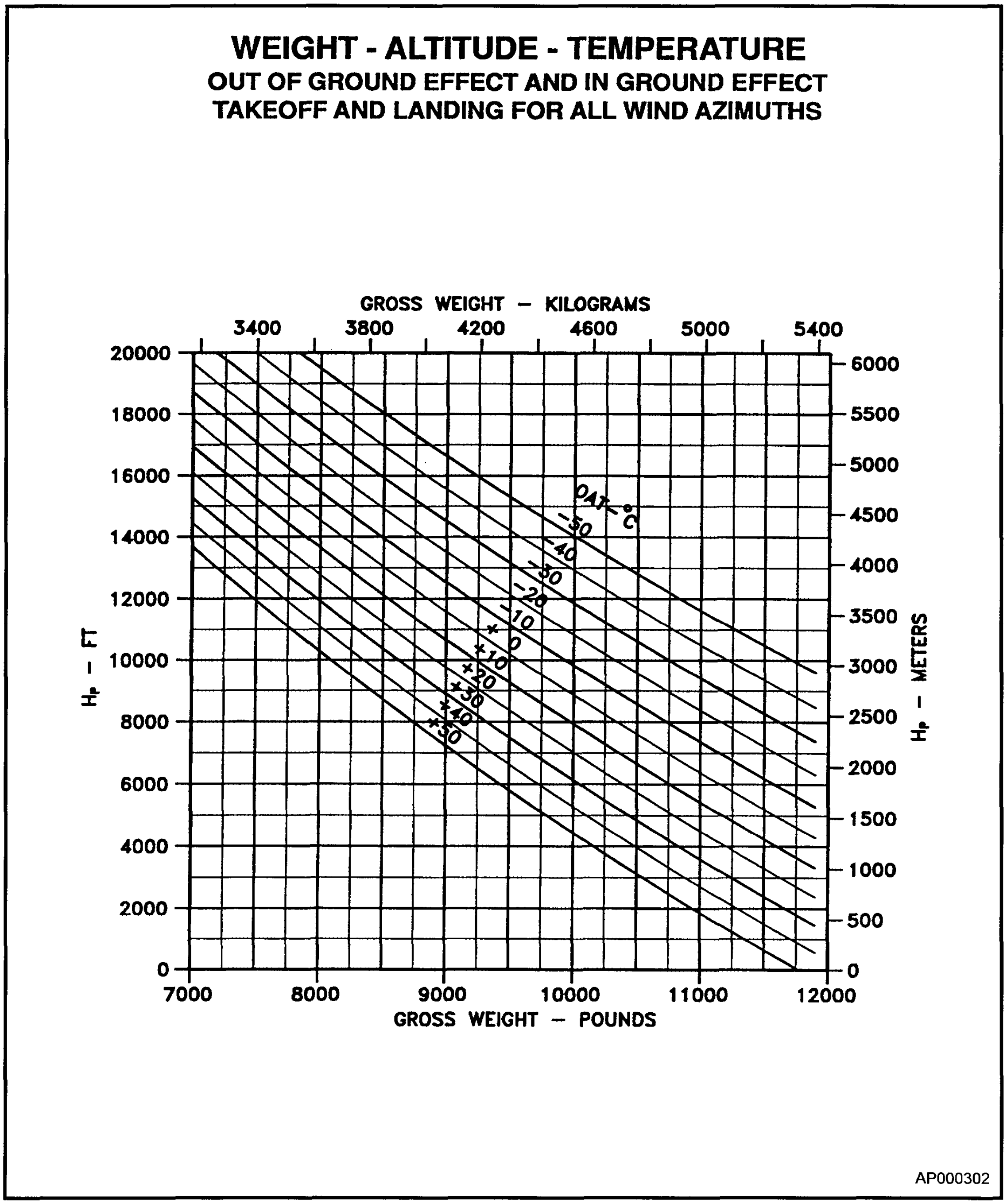

Figure 8-11. WAT chart, all azimuths

Source: C-12-146-000/MB-002

Figure 4-4: Hover Ceiling Chart IGE

Note: This is the same chart as ***Figure 1-1: WAT Chart – IGE***.

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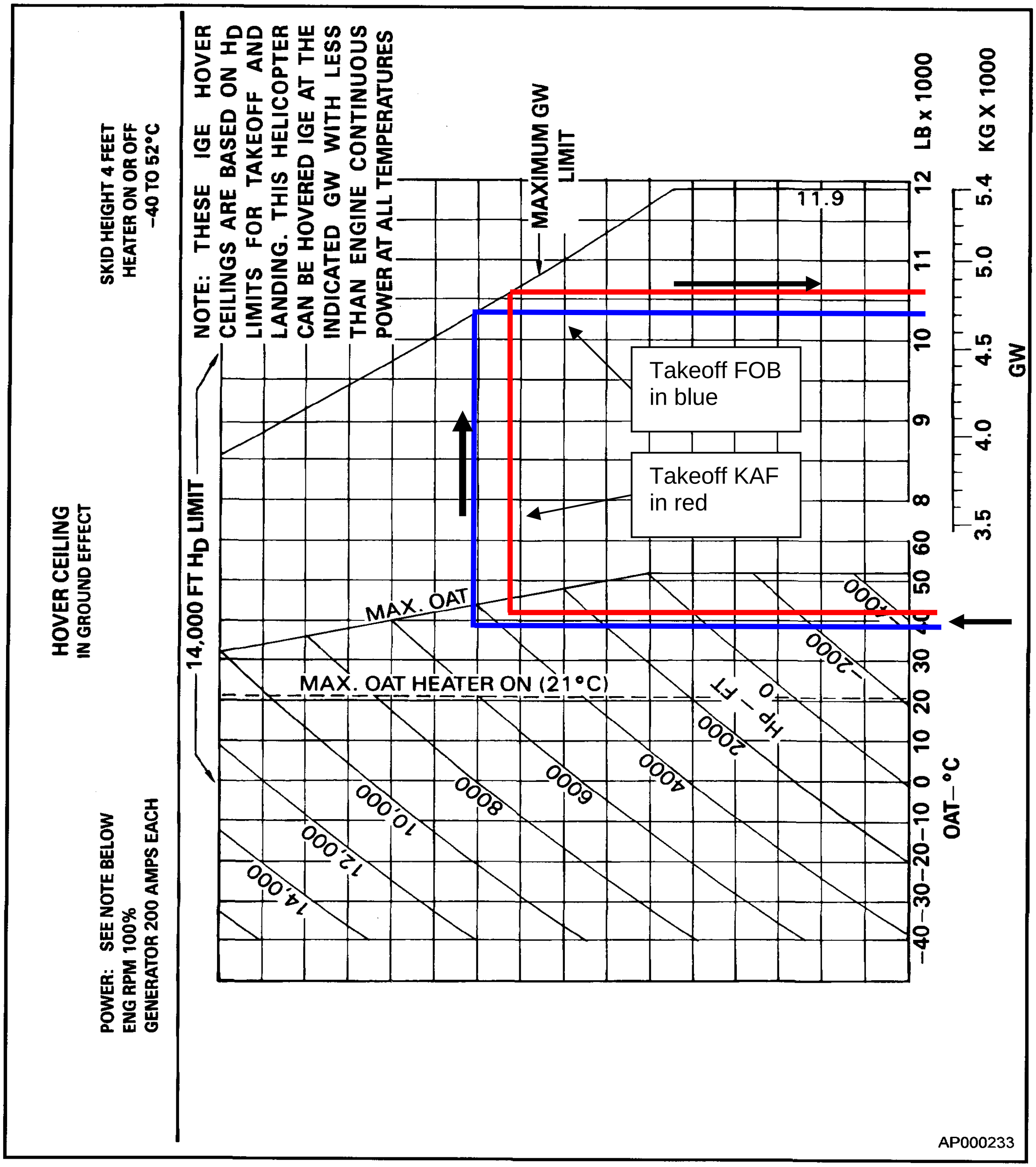


Figure 4-4. Hover ceiling (Sheet 1 of 11)

Source: C-12-146-000/MB-002

Figure 4-4: Hover Ceiling Chart OGE

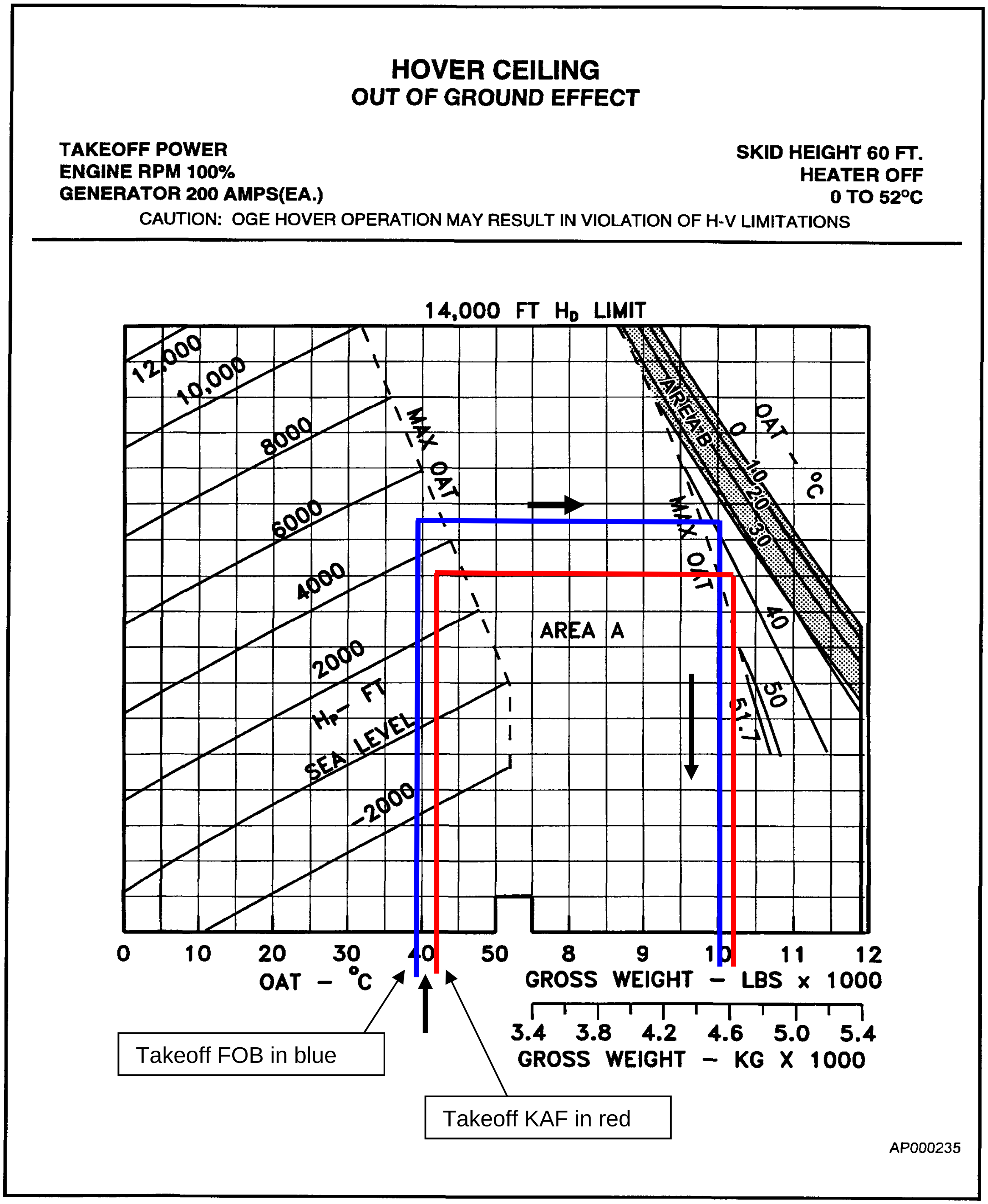
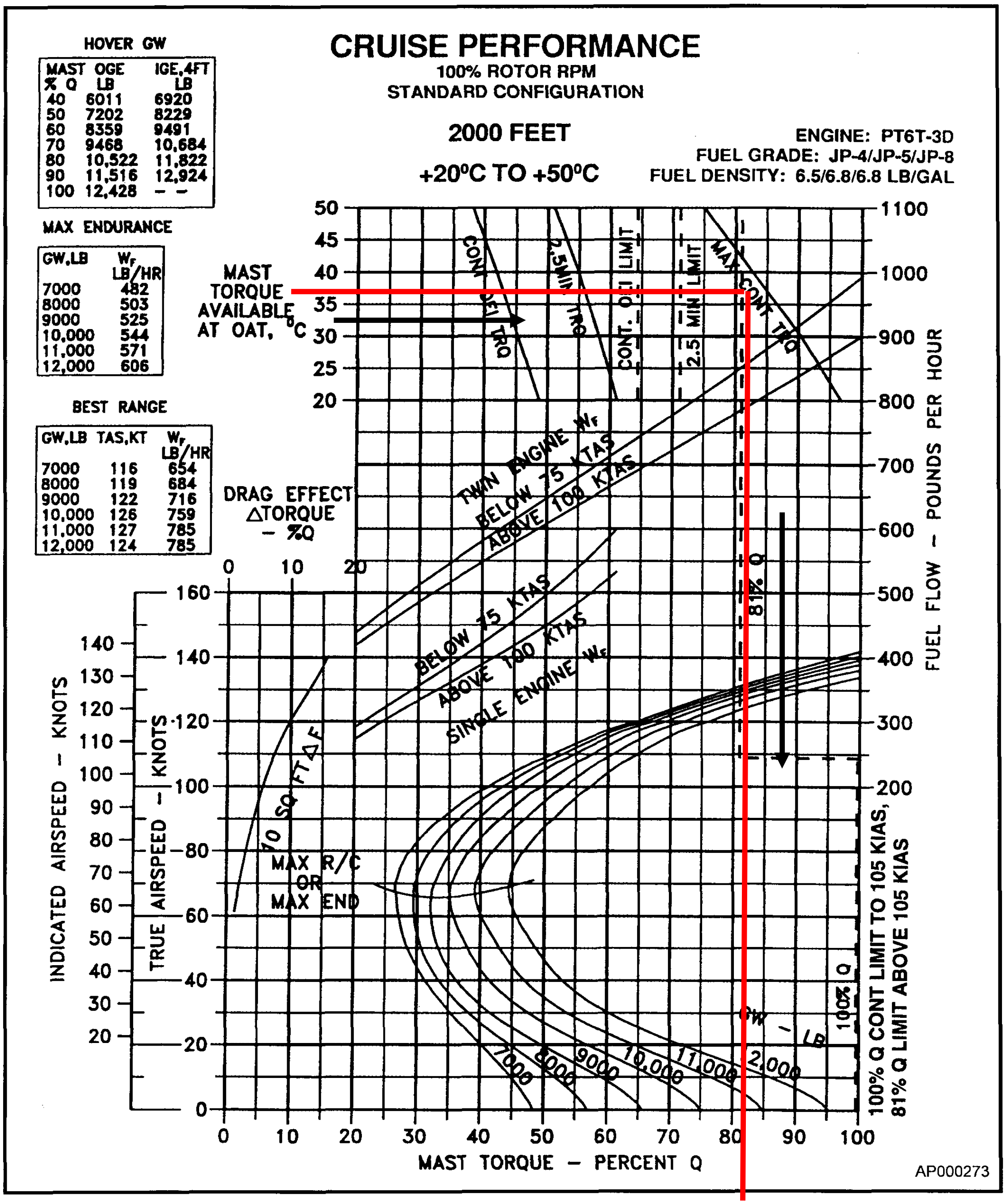


Figure 4-4. Hover ceiling (Sheet 3 of 11)

Source: C-12-146-000/MB-002

Annex D: Cruise Performance Charts

Figure 8-1: Cruise Chart 2000 ft



HOVER GW MAST % Q	OGE LB	IGE,4FT LB
40	6011	6920
50	7202	8229
60	8359	9491
70	9468	10,684
80	10,522	11,822
90	11,516	12,924
100	12,428	– –

MAX ENDURANCE GW,LB	W_F LB/HR
7000	482
8000	503
9000	525
10,000	544
11,000	571
12,000	606

BEST RANGE GW,LB	TAS,KT	W_F LB/HR
7000	116	654
8000	119	684
9000	122	716
10,000	126	759
11,000	127	785
12,000	124	785

Figure 8-1. Cruise chart (Sheet 6 of 24)

Source: C-12-146-000/MB-002

Figure 8-1: Cruise Chart 4000 ft

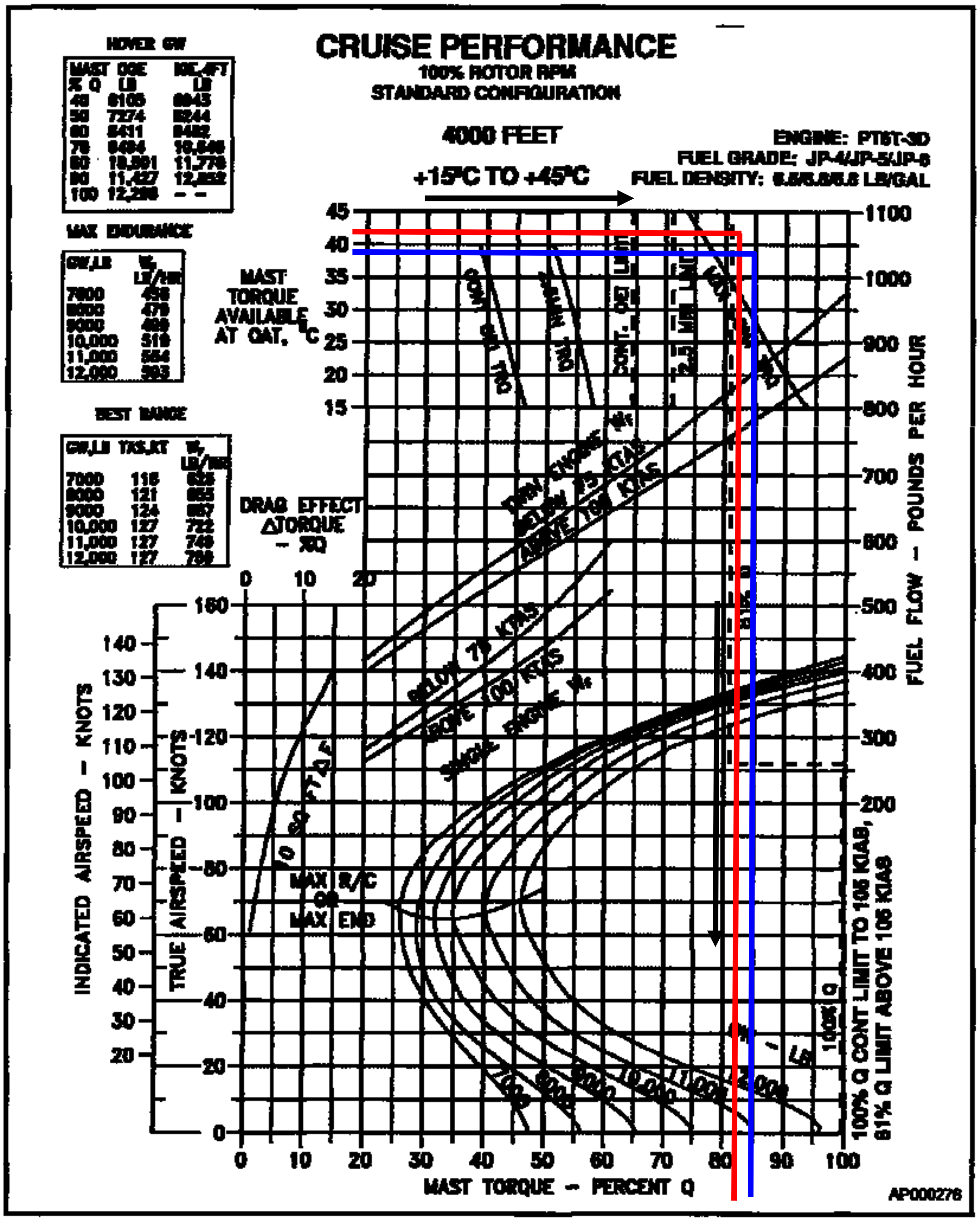


Figure 8-1. Cruise chart (Sheet 9 of 24)

Takeoff KAF in red

Takeoff FOB in blue

Source: C-12-146-000/MB-002

Figure 8-1: Cruise Chart 6000 ft - Afternoon Takeoff FOB

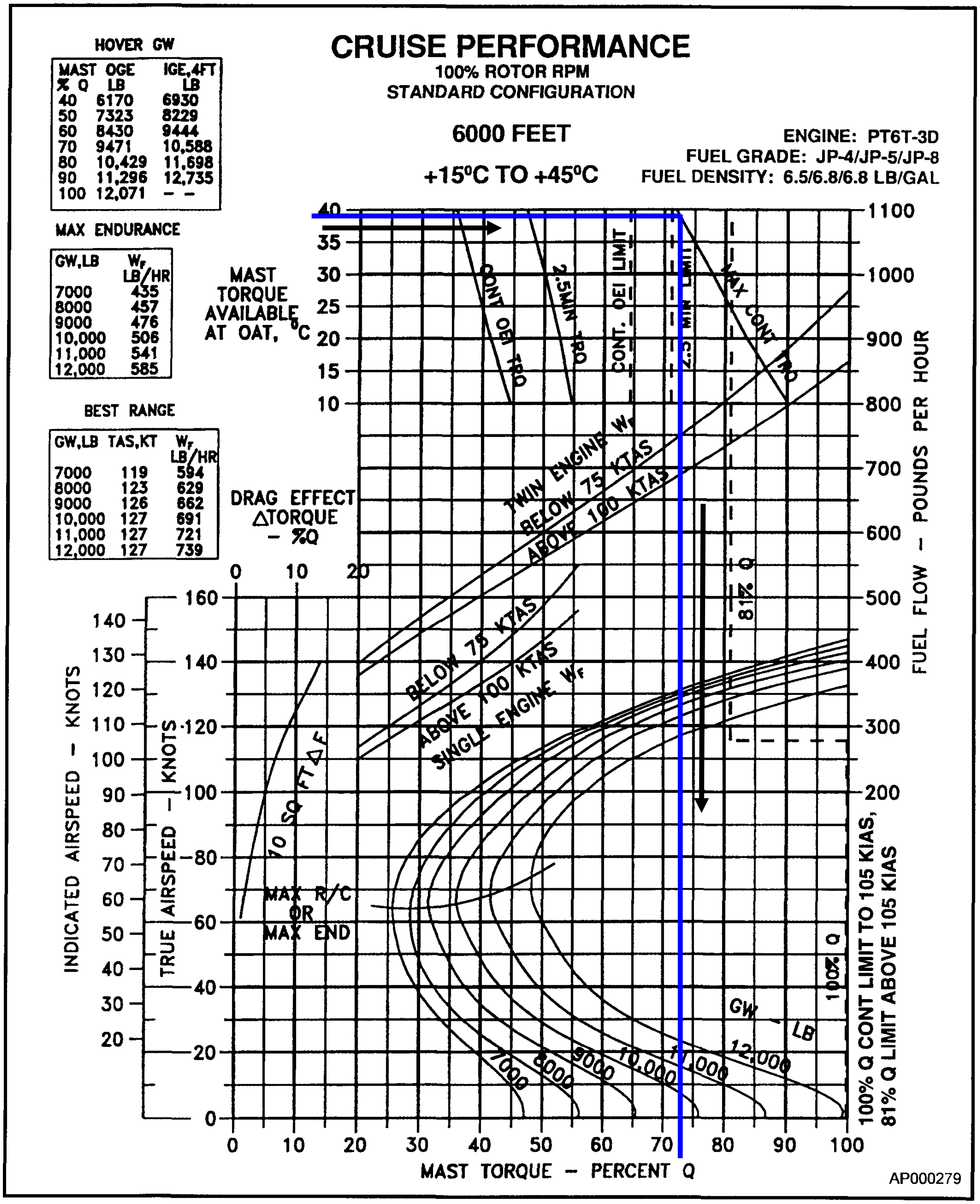


Figure 8-1. Cruise chart (Sheet 12 of 24)

Source: C-12-146-000/MB-002

Annex E: Hover Torque Required Charts

Figure 8-7: Hover Torque Required IGE

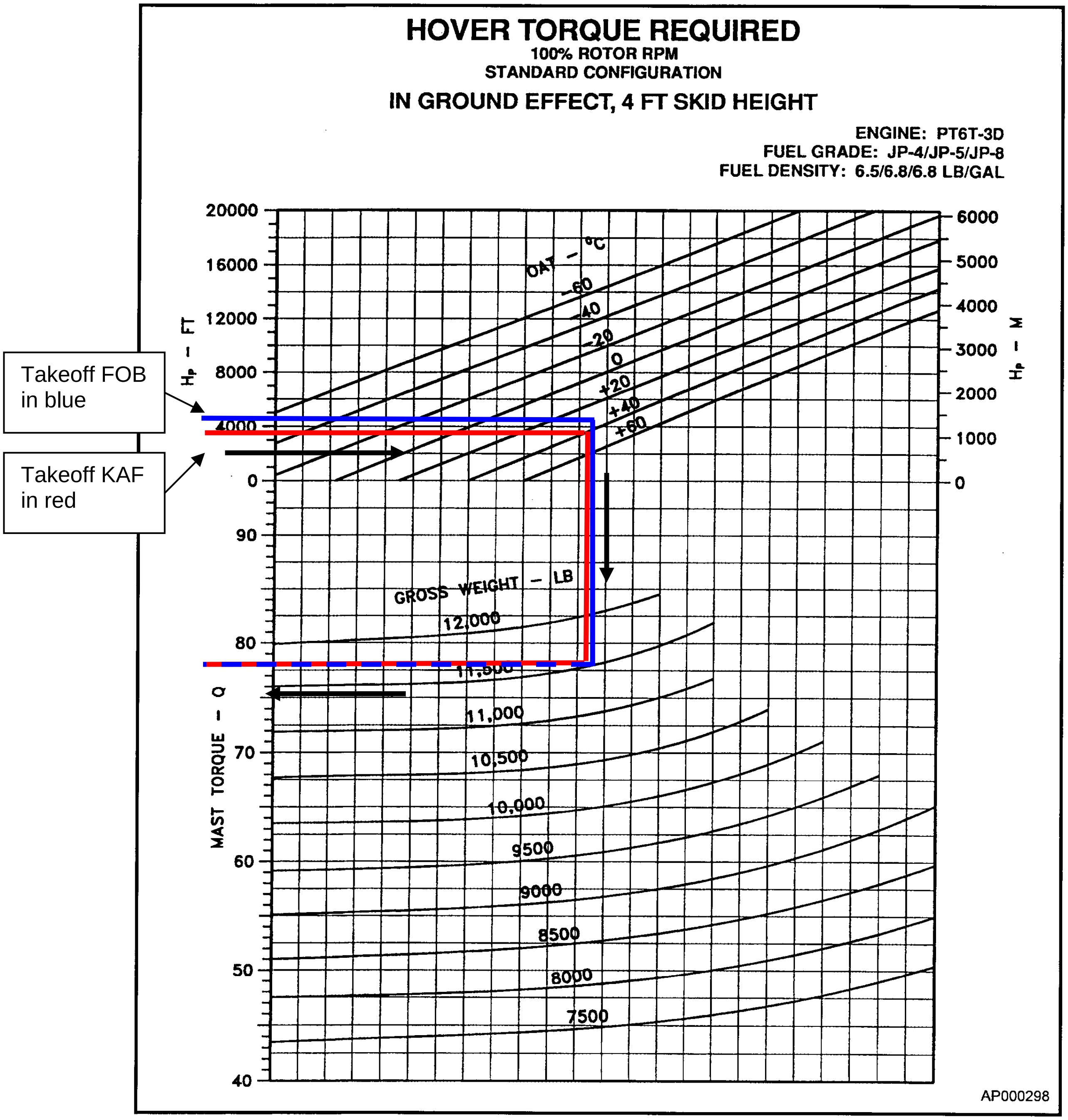


Figure 8-7. Torque required to hover, IGE

Source: C-12-146-000/MB-002

Figure 8-8: Hover Torque Required OGE

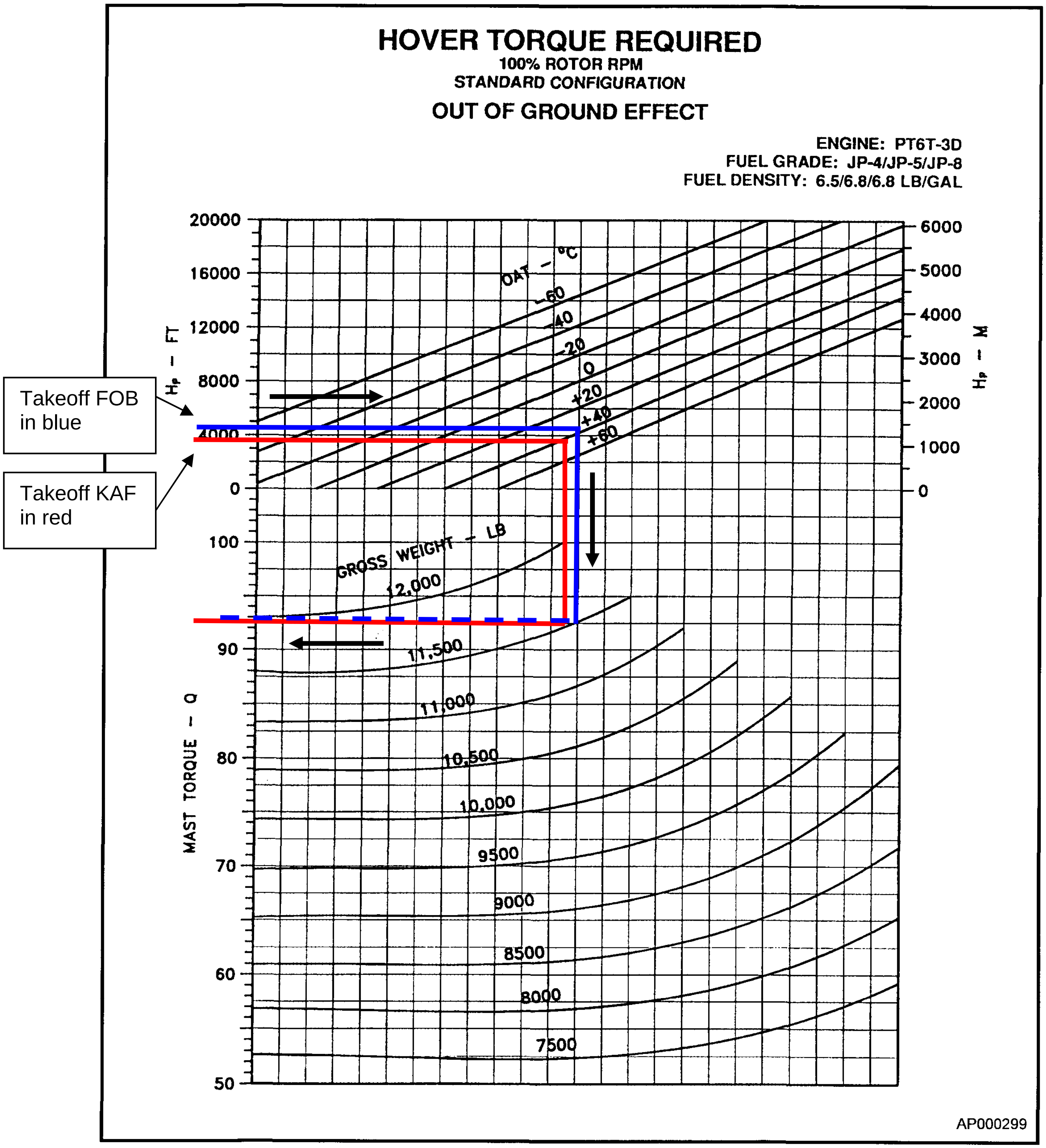


Figure 8-8. Torque required to hover, OGE

Source: C-12-146-000/MB-002

Annex F: Comparative Analysis of Flight Data

1. A comparative analysis of the #2 and the accident aircrafts' flight was conducted using FDR data. The data of interest to the investigation were:

a) Cyclic Position – Longitudinal, Graph 1;

b) Cyclic Position – Lateral, Graph 2;

c) Collective Position[60], Graph 3;

d) Calculated Mast Torque (NRC Method), Graph 4;

e) Revised Calculations (WSM), Graph 5;

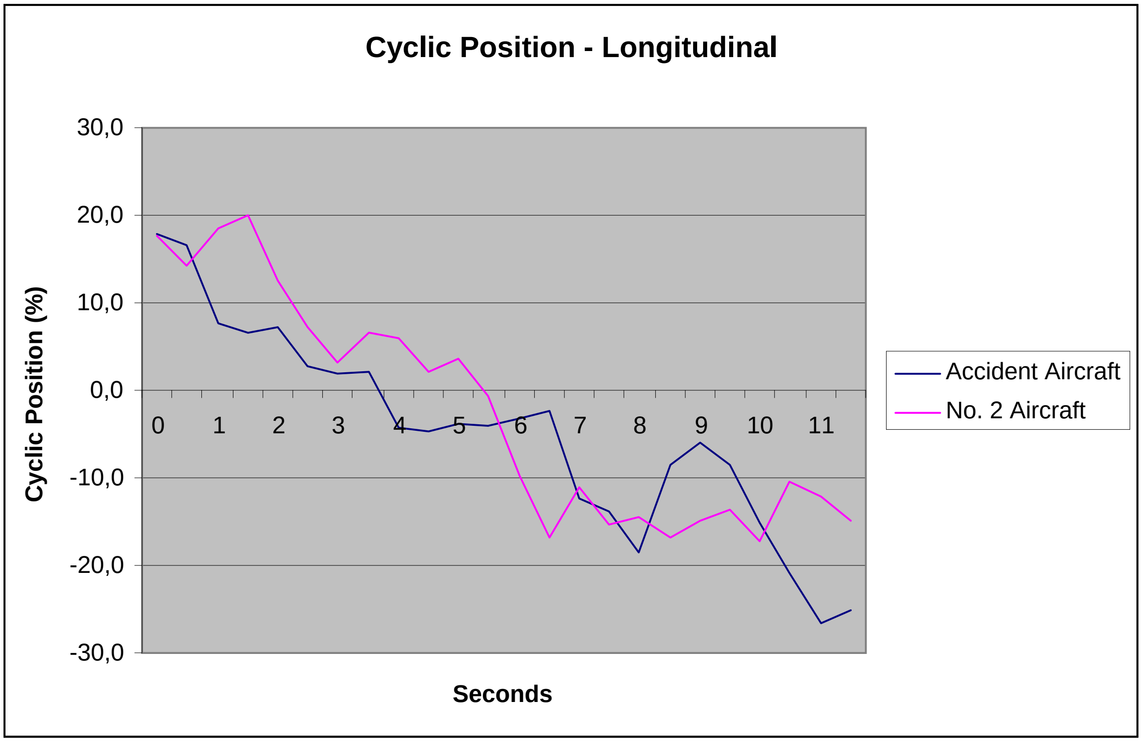
f) Aircraft Heading, Graph 6; and

g) Roll Attitude, Graph 7.

2. A graphical depiction of the data can be found on pages two to seven of this annex.

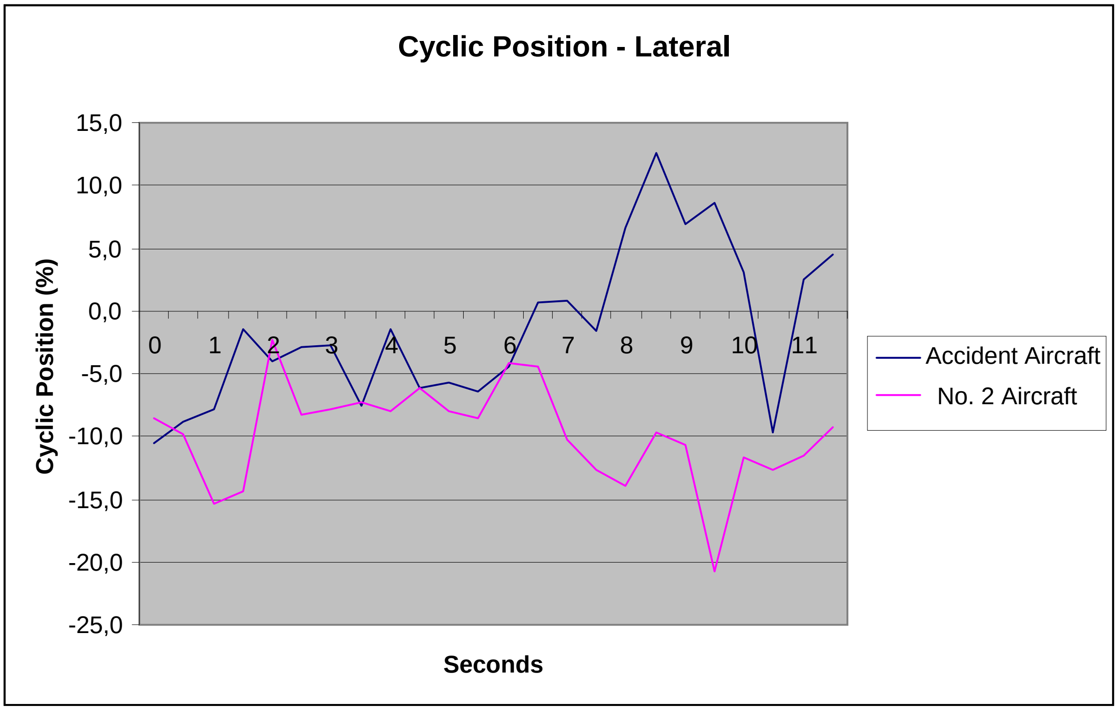
[60] Collective position is represented as a percentage of travel and, while directly related to, is different than Qm.

GRAPHS FROM FDR DATA



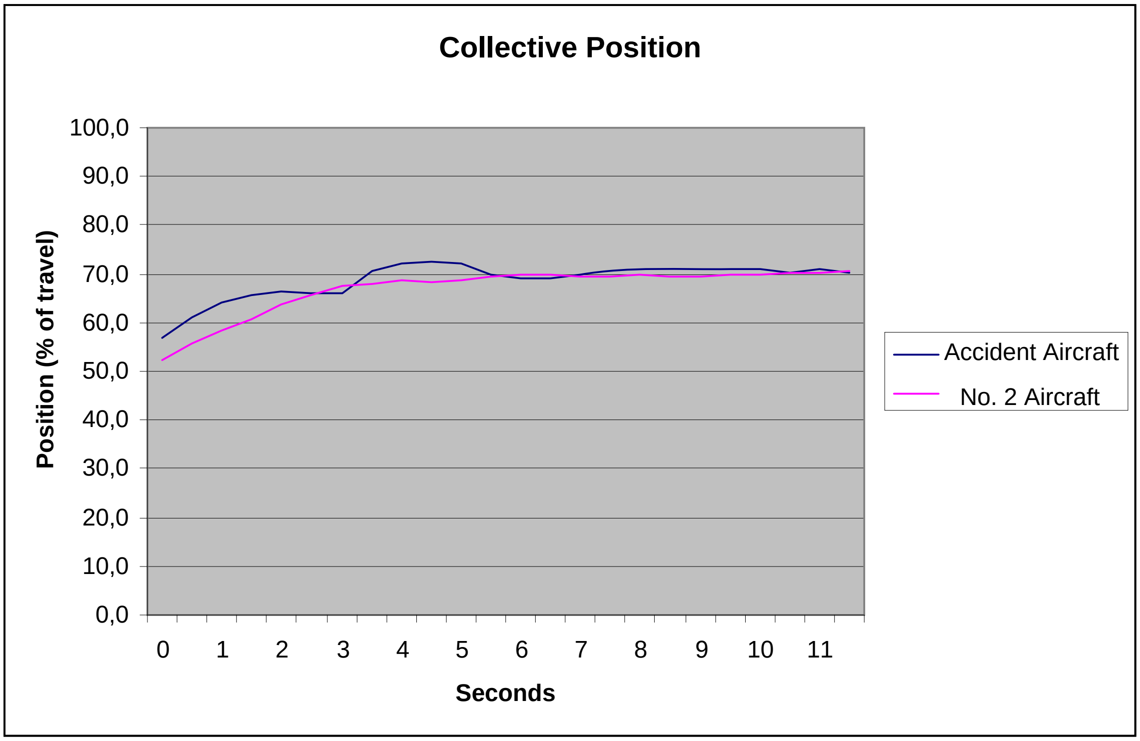
Graph 1 – Cyclic Longitudinal Position

Note: Cyclic position is expressed in percentage of travel. Positive values indicate aft cyclic and negative values indicate forward cyclic.



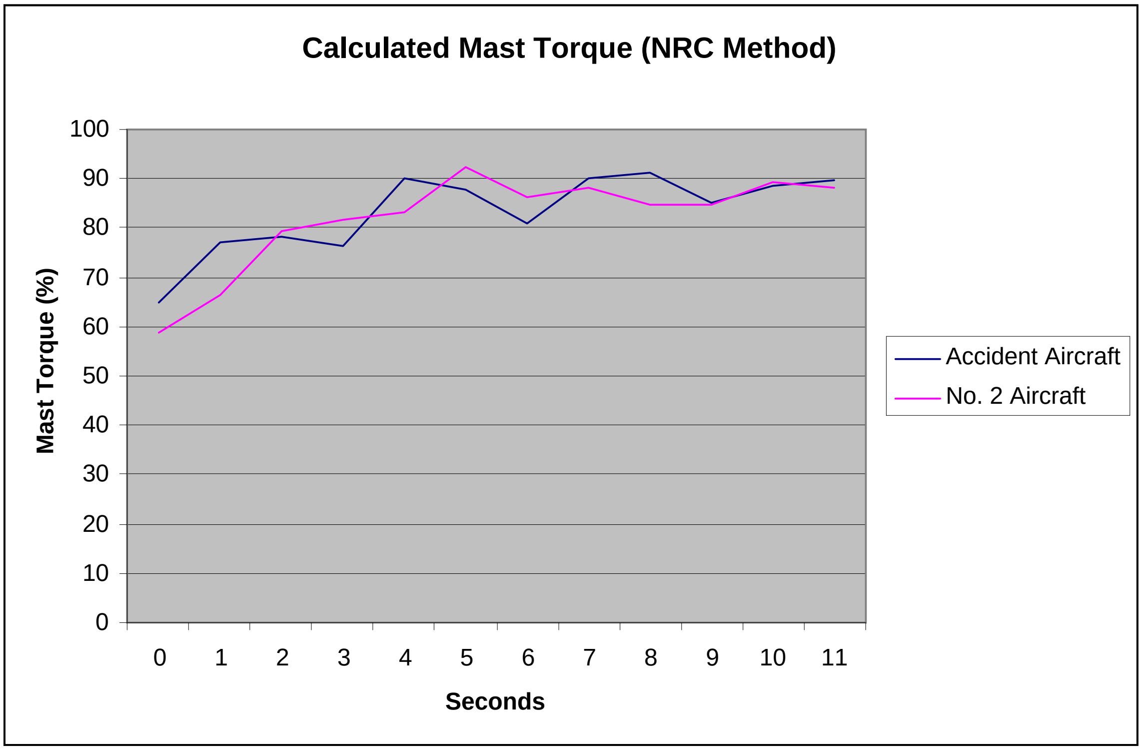
Graph 2 – Cyclic Lateral Position

Note: Cyclic position is expressed in percentage of travel. Positive values indicate right cyclic and negative values indicate left cyclic.



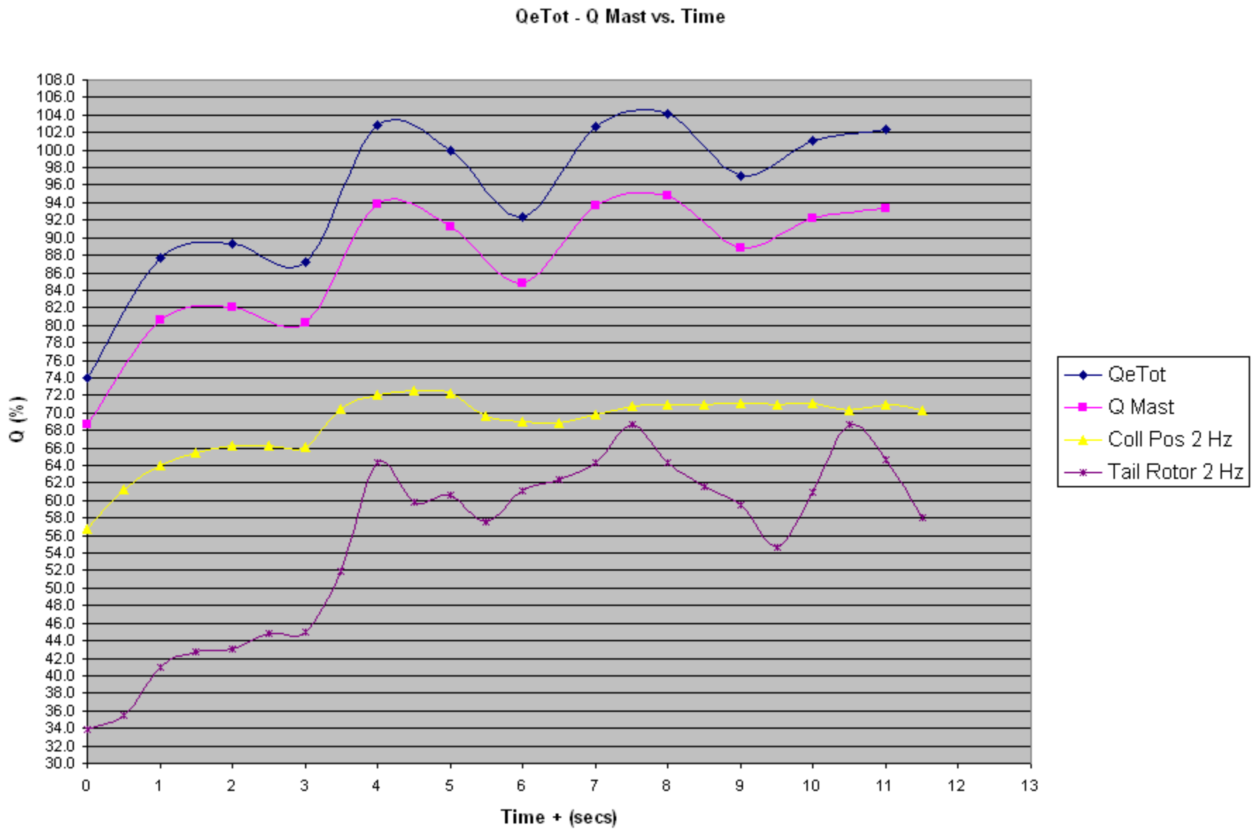
Graph 3 – Collective Position

Note: Collective position is expressed in percentage of travel. While collective position is generally proportional to mast torque, the collective position values are slightly different. Collective position is a physical measurement of the collective position while mast torque is a measure of the torque on the main rotor mast itself. Mast torque may vary depending on wind conditions. (i.e. gusty winds may vary mast torque values with a constant collective position)

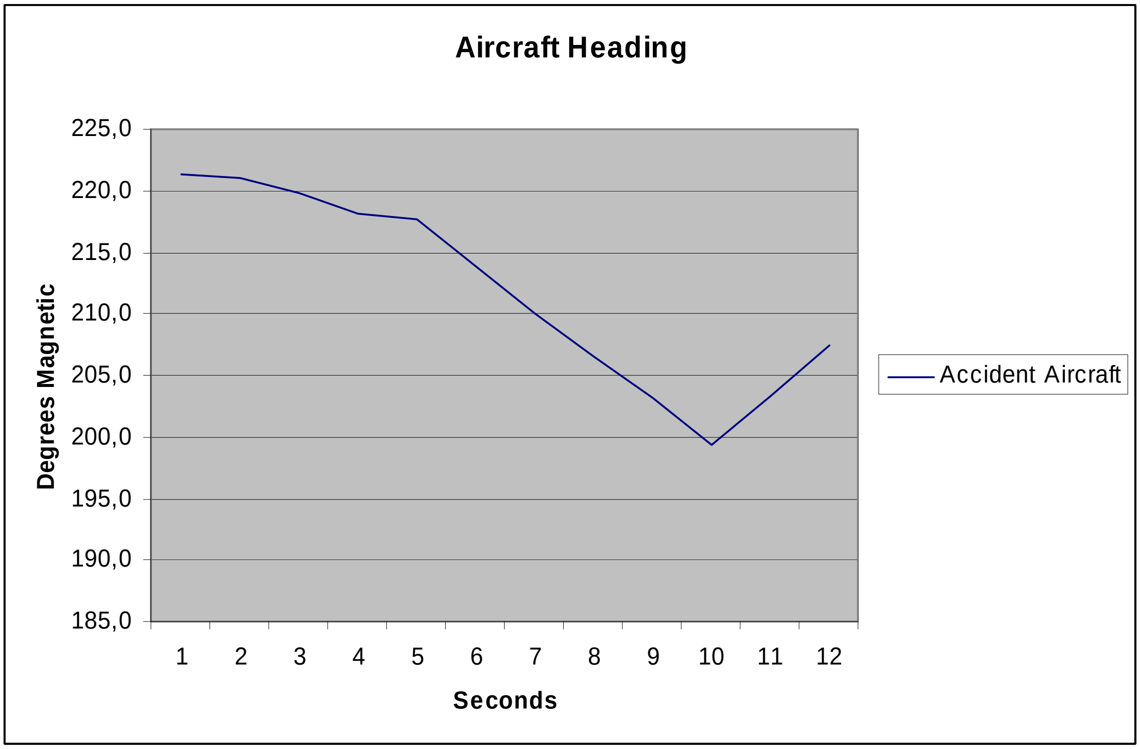


Graph 4 – Calculated Mast Torque

Note: See note at bottom of graph 3. See paragraph 1.19.1

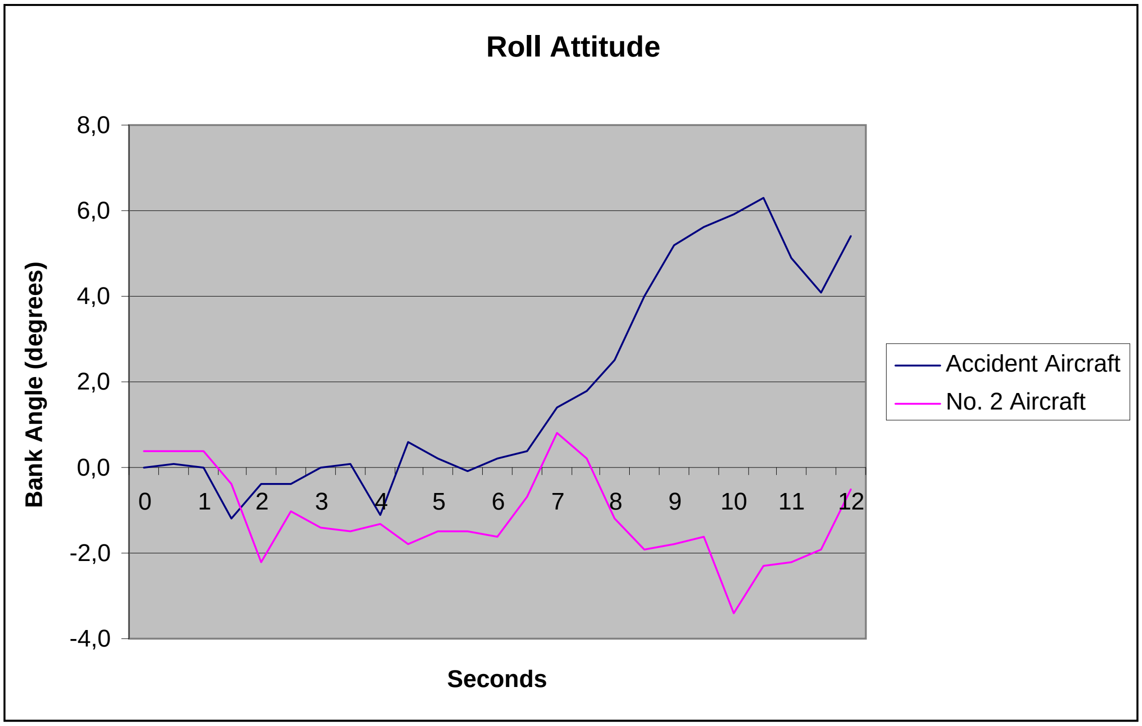


Graph 5 – Revised Calculations CH146434 – (WSM)



Graph 6 – Aircraft Heading

Note: This is for the accident aircraft only.



Graph 7 – Aircraft roll attitude

Note: Aircraft roll attitude is expressed in degrees of bank. Positive values indicate right bank and negative values indicate left bank. The CH146 normally hovers with slight left skid low.

Annex G: DTAES Technical Note 75-00-15

1. The cover page of the technical note is copied here with the entire technical note included in the following pages of this annex.

DTAES 7-5
Flight Sciences

PER NOS AD ASTRA

Technical Note
DTAES 75-09-15

Title:	TAA Review of CH146 AFM Supplement Z60
File Number:	2182DA-11500GR-507-3- VOL 1

Distribution List

References:

A. C-12-146-000-MB/002, “CH146 Griffon Flight Manual”, 2002-01-16, Ch2 2009-02-20.
B. C-12-146-000-MB/Z60, “CH146 Griffon Technical Manual Supplement to CFTO C-12-146-000/MB-002, Operation with Nine Passengers or Less”, DRAFT (various versions/dates).
C. Bell Model 412 Flight Manual Supplement BHT-412-FMS-35.3 & 35.4 "Category B Operations when Configured with Nine or Less Passenger Seats", 10 May 1996, Rev 3, 5 Sep 2000.
D. Bell Model 412 Flight Manual BHT-412-FM3, 01 July 1991.
E. FAA Regulations FAR Part 29 Transport Category Rotorcraft, various amendments.
F. FAA Advisory Circulars Part 29 Transport Category Rotorcraft, various amendments.
G. FAA Type Certificate Data Sheet No. H4SW, Bell Model 412, Revision 28, 19 Jan 2007.

1. AIM / OBJECTIVES

1.1 This technical note records the results of the review of the subject amendment to the CH146 Aircraft Flight Manual (AFM), ref A, and to provide recommendations to TAA staff (DTAES 5-3) for TAA approval of the amendment, as well as to the CH146 SDE and the AFM OPI.

Signature Note: *The final draft of this Tech Note was forgotten and not signed in Oct 2009. Action was taken based on the final draft, and Ref B was released (ref RDIMS AEPM #901049). This Tech Note is now being signed after the fact, for record. There may thus be some small discrepancies between the Tech Note content and actual actions taken.*

[redacted]	Reviewed by: N/A	[redacted]
Date: See Note.	Date:	Date: 22 Mar. 2010

AEPM-#899020-v1A-TECHNICAL_NOTE__DTAES_75-09-15_TAA_Review_of_CH146_AFM_Supplement_Z60__.DOC

1. AIM / OBJECTIVES

1.1 This technical note records the results of the review of the subject amendment to the CH146 Aircraft Flight Manual (AFM), ref A, and to provide recommendations to TAA staff (DTAES 5-3) for TAA approval of the amendment, as well as to the CH146 SDE and the AFM OPI.

2. BACKGROUND

2.1 Following the accident of CH146434 in Afghanistan, it was discovered that some of the hover performance charts in ref A that were being used by aircrew for flight planning do not indicate the appropriate Weight-Altitude-Temperature (WAT) limits for hot/high conditions. Specifically, some the charts do not show the lower WAT limits due to engine temperature limits (ITT limits).

2.2 To address this situation, the AFM OPI, A3 Tac Avn Sys, requested that a new supplement be added to ref A, which would include performance charts suitable for these conditions. A draft supplement, ref B, was prepared by the OEM, Bell Helicopter Textron Canada Limited (BHTCL).

2.3 Ref B is based upon the Category B supplement, ref C, used for the civilian Bell Model 412 AFM, ref D. The ref B supplement is thus based upon the FAA civil airworthiness regulations and standards contained in FAR Part 29 Transport Category Rotorcraft, Ref E, and the associated advisory material in Ref F.

3. DISCUSSION

3.1 In order to review Ref B, the basis of the performance information contained in Ref A needed to be understood. Various meetings and telecons were held with BTHCL representatives to explain the origins of the performance information used in refs C and D, and thus refs A and B. No formal documentation, such as certification reports, were provided for review, so the information from the OEM is testimonial in nature. The following are the key findings.

3.2 GENERAL

3.2.1 The performance limitations and charts in the basic civilian AFM, ref D, are in accordance with FAR 29 Category A requirements. (Note: the actual Cat A takeoff and landing profile information is not contained in the basic AFM, and is instead provided in a Supplement for Cat A Operations.).

3.2.2 In accordance with the Model 412 basis of certification for Part 29 Category A, given at Ref G, both the hover in ground effect (HIGE) WAT chart and the Height-Velocity (H-V) diagram are considered as airworthiness limitations. In Category B, the H-V diagram is no longer a limitation, and the HIGE WAT chart requires less-restrictive constraints, thus permitting higher WAT limits.

3.2.3 For either Cat A or B, the hover out of ground effect (HOGE) charts were not required by the Model 412CF basis of certification and are provided as performance info only. (This requirement was not added to FAR 29, Ref E, until 2008, which is some 13 years after the certification date of the Model 412CF on Ref G.)

3.3 CAT A (BASIC FLIGHT MANUAL)

3.3.1 CAT A HIGE

3.3.1.1 The HIGE WAT chart in the basic flight manual (Fig 1-1 of Ref A) has an upper limit at high WAT combinations equivalent to a Referred Weight1 (Wref) of 13200 [lb]. This chart provides the limitations for maximum safe takeoff weight.

3.3.1.2 The chart is based upon flight testing at this Wref, in winds from all azimuths, and with the effects of a control actuator failure ("hard-over"). The testing revealed no control authority limitations in wind speeds up to the limits in Fig 1-4 of Ref A. Fig 1-4 does highlight the relative wind azimuth angles in which the least control authority is available.

3.3.1.3 The H-V diagram, Fig 1-5 of Ref A, is valid for the WAT limits in Fig 1-1.

3.3.2 CAT A HOGE

3.3.2.1 The HOGE charts contained in Ref A Fig 4-4 (multiple sheets) are provided for performance information only.

3.3.2.2 Area A on these charts represents the area covered by the HIGE chart, with Wref up to 13200 [lb]. Area B has Wref extending up to 14400 [lb], which provides additional hover capability that may be used OGE. As the Wref in Area B exceeds the max takeoff weight permitted by the HIGE chart, Area B can be achieved only in external load operations.

3.3.2.3 Just as for the HIGE chart, Area A of the HOGE chart is valid for winds from all azimuths at speeds up to the limits in Fig 1-4 of Ref A, and includes the effects of a control actuator failure. Fig 1-4 also identifies the critical relative wind azimuths where control margins are lowest.

3.3.2.4 Area B of the HOGE chart is valid only outside the critical wind azimuth angles of Fig 1-4 of Ref A. Within the critical azimuth areas, control authority issues may be encountered for left tail rotor pedal or aft cyclic, particularly in the effect of a control actuator failure.

3.3.2.5 The Cat A HOGE charts feature reductions in maximum Wref based on Outside Air Temperature (OAT), which are due to the engines reaching temperature limits.

3.3.2.6 The H-V diagram, Fig 1-5 of Ref A, is not valid in Area B, as the flight testing did not include demonstrations of landings following an engine failure at these higher Wref.

1 Bell uses the term "referred weight" to represent W/σ, "weight-over-sigma" (where σ is the atmospheric density ratio $\rho/\rho 0$, and ρ0 is the standard sea level air density), however other sources define referred weights differently. For this technical note, Wref is based on the Bell definition.

3.4 CAT B (FLIGHT MANUAL SUPPLEMENT)

3.4.1 CAT B HIGE

3.4.1.1 The HIGE chart in the Model 412 Cat B supplement, Ref C, is based upon flight testing at Wref up to 15000 [lb], compared with only 13200 [lb] that was used for Cat A in the basic flight manual. This permits operations at higher takeoff weights than are permitted by Cat A.

3.4.1.2 In addition, the Cat B certification raised the density altitude (DA) limit to 16000 [ft] from the 14000 [ft] that was used for Cat A. The Wref at 16000 [ft] is reduced by a small percentage from that at 14000 [ft], which the FAA required to be applied based on the flight test data that was available.

3.4.1.3 A fundamental difference from Cat A is that the Cat B certification did not require controllability assessments to include the effects of a control actuator failure.

3.4.1.4 Unlike the Cat A flight testing where HIGE controllability demonstration included winds from all azimuths, the Cat B flight testing demonstrated relative wind only at forward azimuth angles. Based on this, the FAA credited the Model 412CF with relative winds demonstrated only within +/- 45 degrees of the nose up to 14000 [ft] DA, and within +/- 30 degrees up to 16000 [ft] DA. Outside of these azimuths, control authority may be limited.

Note however that this applies only to the portion of the HIGE WAT envelope that was added by the Cat B certification, i.e., at Wref above 13200 [lb]. Below 13200 [lb] Wref, the relative wind was demonstrated at all azimuths as per the Cat A certification, explained above at 3.3.1.2. Also note that the wind speeds used for the Cat B certification were higher at higher DA than was the case for Cat A.

3.4.2 CAT B HOGE

3.4.2.1 The Cat B HOGE charts are based on Wref up to 14150 [lb], or about 250 [lb] less than was the case for Cat A at 14400 [lb], despite Bell intending no change for the Cat B certification. Bell reports this is due to an evolution in the FAA's willingness to accept flight test substantiation without witnessing it, and as a consequence they gave "less credit" during the Cat B certification program than they had in the original Cat A program, despite it being the same aircraft at the same flight conditions.

3.4.2.2 Note that the HOGE Wref of 14150 [lb] is also significantly less than the HIGE Wref of 15000 [lb]. This signifies that the additional takeoff weight permitted by the Cat B certification in excess of 14150 [lb] is useable only with an IGE takeoff, i.e., with transition through forward flight to climb profile while still IGE.

3.4.2.3 Just as for the Cat B HIGE chart, the FAA required that the Wref at 16000 [ft] DA was reduced from that at 14000 [ft] based on the available flight test data.

3.4.2.4 Just as for Cat A, the Cat B HOGE charts feature reductions in Wref based on OAT, due to the engines reaching temperature limits.

3.4.2.5 Considering that Cat B HOGE limits were intended to be that same as Cat A, and that they are nearly identical, the relative wind limits and azimuth considerations are no different than as in Ref A for the Cat A HOGE charts.

3.4.2.6 The H-V diagram is valid to approximately 14500 [lb] Wref (close, but not identical, to the Wref of the HOGE charts, which is 14150 [lb]).

3.5 OTHER FLIGHT MANUAL ISSUES

3.5.1 Ref A includes some hover performance charts in Section 8, at Figs 8-11, 12, and 13. These charts are not included in the Model 412 AFM, Ref D, and were created specifically for the CH146 at DND/CF request. The technical basis for these charts is not known at this time. Unfortunately these charts do not reflect the WAT reductions due to engine temperature limits at higher air temperatures. If used by aircrew for flight planning in conditions where engine temperature limits could be encountered, the charts may suggest more performance capability then is actually available. This could contribute to a flight safety situation.

3.5.2 Ref A includes a HIGE chart at Fig 1-1A, which is a copy of the Fig 8-13. This is presented as the HIGE WAT limitation when operating with 9 passengers or less, i.e., a Cat B limitation. However it is presented in a Cat A basic flight manual. The chart was inserted here in a temporary revision of Ref A prior to being fully incorporated in Change 2 or Ref A. At the same time the title of Fig 1-1 was changed to state it applies only to 10 passengers or more. These revisions did not receive TAA review and approval.

3.5.3 Some of the hover charts include the basic heater in addition to the winterization heater. The CH146 is equipped only with the latter, and charts for the former, which apply to the Model 412, should be removed.

3.5.4 It was discovered that HIGE chart for Maximum Continuous Power contained in Ref C and proposed for Ref B is in error, as it reflects the incorrect performance limitations.

3.5.5 Regardless of the certification basis for Ref A being FAR 29 Cat A, it is well known that the CH146 is not operated according to Cat A performance information or operating regulations. Further, it is perhaps not operated according to Cat B, either. CH146 operators appear to have no knowledge of the Cat A and B technical limitations of their aircraft and the associated operating rules that apply. Thus the significance to any references to Cat A or B in the flight manual are not understood by aircrew. CH146 operations are generally conducted as directed by the CH146 Standard Manoeuvres Manual.

3.5.6 The Ch 2 of Ref A did not receive TAA review and approval. Ch 2 included the permanent incorporation of a number of temporary revisions, and an unknown number of additional new revisions. Some of the content may have received TAA review during the associated AMAF process, where applicable, however this does not cover all of the revisions, nor constitute a proper TAA review and approval of the AFM amendments.

3.6 SUPPLEMENT STRATEGY

3.6.1 Through several revisions of the Ref B supplement, the immediate strategy developed as follows.

3.6.1.1 Ref B should be added to Ref A, while simultaneously removing Figs 1-1A, 8-11, 12, and 13 entirely from Ref A, and restoring the title of Fig 1-1 in Ref A.

3.6.1.2 Ref B would be titled "Operations with Nine Passengers or Less" rather than Ref C's title "Category B Operations when Configured with Nine or Less Passenger Seats". This removes the reference to "Cat B" which is not understood by CH146 aircrews. Further, for CF operations, the concern is with the passengers on board rather than the seat configuration. These changes add flexibility while maintaining the same level of safety intended by the FAR 29 Cat B standards.

3.6.1.3 The Ref B supplement would have all HOGE charts removed, and instead the HOGE charts in the basic flight manual Ref A would be used. This was justified due to their similarity and Bell's original intention that they be identical.

3.6.1.4 Ref B would have the incorrect HIGE chart for Maximum Continuous Power removed.

3.6.1.5 The maximum DA in Ref B would be contained at 14000 [ft] versus the 16000 [ft] in the civil supplement Ref C. This is done only as a short-term measure to ensure commonality with Ref A.

3.6.1.6 The wind charts would be harmonized to use the Cat A wind speed limits, as contained at Fig 1-4 of Ref A. The critical azimuth angles for Cat B HOGE would be the same as Cat A HOGE. Similarly, the critical azimuth angles for Cat B HIGE at Wref below 13200 [lb] would be the same as for Cat A HIGE, however at Wref above 13200 [lb], it would be as per the civil supplement, Ref C. These changes were made to clarify the cautionary regions of the relative wind envelope, as well as to simplify the presentation of this information.

3.6.1.7 As the hover charts currently available were based on the Model 412 150-amp generator, whereas the CH146 has 200-amp generators, a limitation is inserted into Section 1 of Ref B requiring max generator load not exceed 150 amps each. This is an interim measure until the Cat B charts based on the 200-amp generator are provided.

3.6.1.8 A General Information section would be added to the front of Ref B, indicating: the changes that the Cat B supplement brings over the Cat A certification basis of the basic flight manual; any increase in risk of using Cat B compared with Cat A; and the derivation basis for Ref B being Ref C, as explained in this technical note.

3.6.2 The longer term strategy should include:

3.6.2.1 A full TAA review and approval of Ref A, Change 2.

3.6.2.2 An assessment of 1 Cdn Air Div of the risk inherent with adopting Cat B operations (or a derivative) as the primary performance limitations in Ref A, rather than Cat A. Should this be accepted, Ref A could be converted to a set of performance limitations more suitable to CH146 operations, such as those derived from Cat B. Where beneficial, such as for civilian and VIP operations, Cat A performance provisions should be retained as a supplement to the flight manual.

3.6.2.3 Inclusion of the 16000 [ft] DA limit in Ref A.

3.6.2.4 Harmonization of the confusing critical relative wind azimuth information for the various hover charts. Where available, additional flight test information could be used to expand this information beyond that provided during the civil certification programs.

3.6.2.5 Update hover charts to be based on the correct equipment, for example, 200-amp generator and winterization heater.

3.6.2.6 Inclusion of the correct HIGE chart for Maximum Continuous Power.

4. CONCLUSIONS

4.1 The actions explained at 3.6.1 should be taken to secure TAA approval of Ref B, and at 3.6.2 to obtain likewise for Ref A.

5. RECOMMENDATIONS

5.1 The actions at 3.6.1 should be incorporated into Ref B before its initial release.

5.2 Upon completion of 3.6.1, TAA Approval should be given to Ref B.

5.3 The actions at 3.6.2 should be incorporated into Refs A and B as soon as practicable.

5.4 Upon completion of 3.6.2, Ref A should be given TAA Approval.

Distribution List

Action

DAEPM(TH) 4-6

Info

DTAES 5-3

1 Cdn Air Div A3 Avn Tac Sys

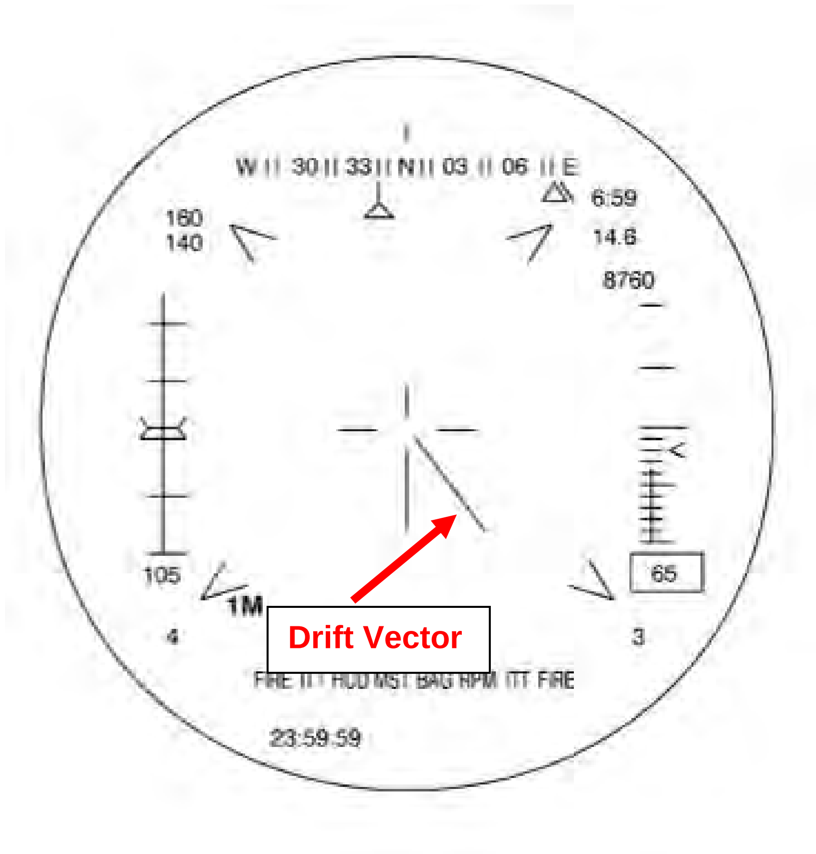
Annex H: ROTO 6 Performance Chart

		20	25	30	35	40	45	50
3500'	OGE WAT Takeoff WT / Q	11,400 / 89	11,300 / 88	11,100 / 86	10,900 / 84	10,700 / 83	10,500 / 81	10,300 / 79
	Twin Engine 810 ITT OGE WT / Q	11,700 / 92	11,400 / 89	11,000 / 85	10,600 / 82	10,300 / 78	9,900 / 75	9,600 / 72
	IGE WAT Takeoff WT / Q	11,400 / 76	11,300 / 76	11,100 / 74	10,900 / 72	10,700 / 71	10,500 / 69	10,300 / 68
	Twin Engine 810 ITT 4' WT / Q	11,900 / 92	11,900 / 89	11,900 / 85	11,800 / 82	11,500 / 78	11,200 / 75	10,800 / 72
	Max 810 WT / Q for IGE T/O +5%	11,900 / 87	11,900 / 84	11,800 / 80	11,400 / 77	10,900 / 73	10,600 / 70	10,200 / 67
4000'	OGE WAT Takeoff WT / Q	11,200 / 87	11,000 / 86	10,800 / 84	10,600 / 82	10,500 / 81	10,300 / 79	10,200 / 78
	Twin Engine 810 ITT OGE WT / Q	11,500 / 90	11,200 / 87	10,800 / 84	10,400 / 80	10,100 / 77	9,800 / 74	9,400 / 70
	IGE WAT Takeoff WT / Q	11,200 / 75	11,000 / 73	10,800 / 71	10,600 / 70	10,500 / 69	10,300 / 68	10,200 / 67
	Twin Engine 810 ITT 4' WT / Q	11,900 / 90	11,900 / 87	11,900 / 84	11,700 / 80	11,300 / 77	11,000 / 74	10,500 / 70
	Max 810 WT / Q for IGE T/O +5%	11,900 / 85	11,900 / 82	11,600 / 79	11,100 / 75	10,800 / 72	10,500 / 69	9,900 / 65
4500'	OGE WAT Takeoff WT / Q	11,000 / 85	10,800 / 84	10,600 / 82	10,400 / 80	10,300 / 79	10,000 / 77	9,900 / 76
	Twin Engine 810 ITT OGE WT / Q	11,300 / 88	10,900 / 85	10,600 / 82	10,200 / 78	10,000 / 76	9,600 / 72	9,300 / 69
	IGE WAT Takeoff WT / Q	11,000 / 73	10,800 / 71	10,600 / 70	10,400 / 68	10,300 / 68	10,000 / 66	9,900 / 65
	Twin Engine 810 ITT 4' WT / Q	11,900 / 88	11,900 / 85	11,800 / 82	11,500 / 78	11,200 / 76	10,800 / 72	10,400 / 69
	Max 810 WT / Q for IGE T/O +5%	11,900 / 83	11,700 / 80	11,300 / 77	10,900 / 76	10,600 / 71	10,200 / 67	9,800 / 64

OGE WAT Takeoff WT / Q		This is the most you can lift OGE based on the ability of the rotors to produce lift/thrust
Twin Engine 810 ITT OGE WT / Q		This is the most you can lift OGE based on the ability of the engines to produce power
IGE WAT Takeoff WT / Q		This is the most you can lift IGE based on the ability of the rotors to produce lift/thrust
Twin Engine 810 ITT 4' WT / Q		This is the most you can lift IGE based on the ability of the engines to produce power
Max 810 WT / Q for IGE T/O +5%		This is the most you can lift IGE with 5% remaining for rotation based on the engines ability to produce power

Note: Although unofficial, this chart also indicated that the accident aircraft was overweight, even if only using 4500' HD and 40ºC OAT.

Annex I: DAY-HUD and NVG-HUD Hover Page Symbology



Notes:

1. The drift vector as currently displayed would indicate aircraft movement in a direction of approximately 45º to the right and rear.

2. The hover velocity vector symbol is a single line with one end point centered on the HUD display. The symbol depicts aircraft drift magnitude and direction over a range from zero to 10 knots groundspeed and from 0ºM to 359ºM. As speed increases the symbol elongates. The direction of the line from the centre of the display indicates aircraft drift direction relative to aircraft heading. Above 10 knots the symbol blanks.

Annex J: CH146 Emergency Procedures

(Source: CH146 Flight Crew checklist – C-12-146-000/MC-002)

ENGINE FIRE

Fault Condition: Engine Fire

On Ground:

Corrective Action:	**1. Both Throttles**	**CLOSE**
	2. FIRE PULL Handle (affected engine)	**PULL**
	3. FIRE EXT Switch	**MAIN, then RESERVE**
	4. Emergency Ground Egress	

EMERGENCY GROUND EGRESS

Corrective Action:	**1. Throttles**	**CLOSE**
	2. BATTERY BUS Switches	**OFF**
	3. Rotor Brake	**AS REQUIRED**
	4. Door	**OPEN/JETTISON**
	5. Exit Aircraft	

Annex K: CH146 Power Performance Software Output

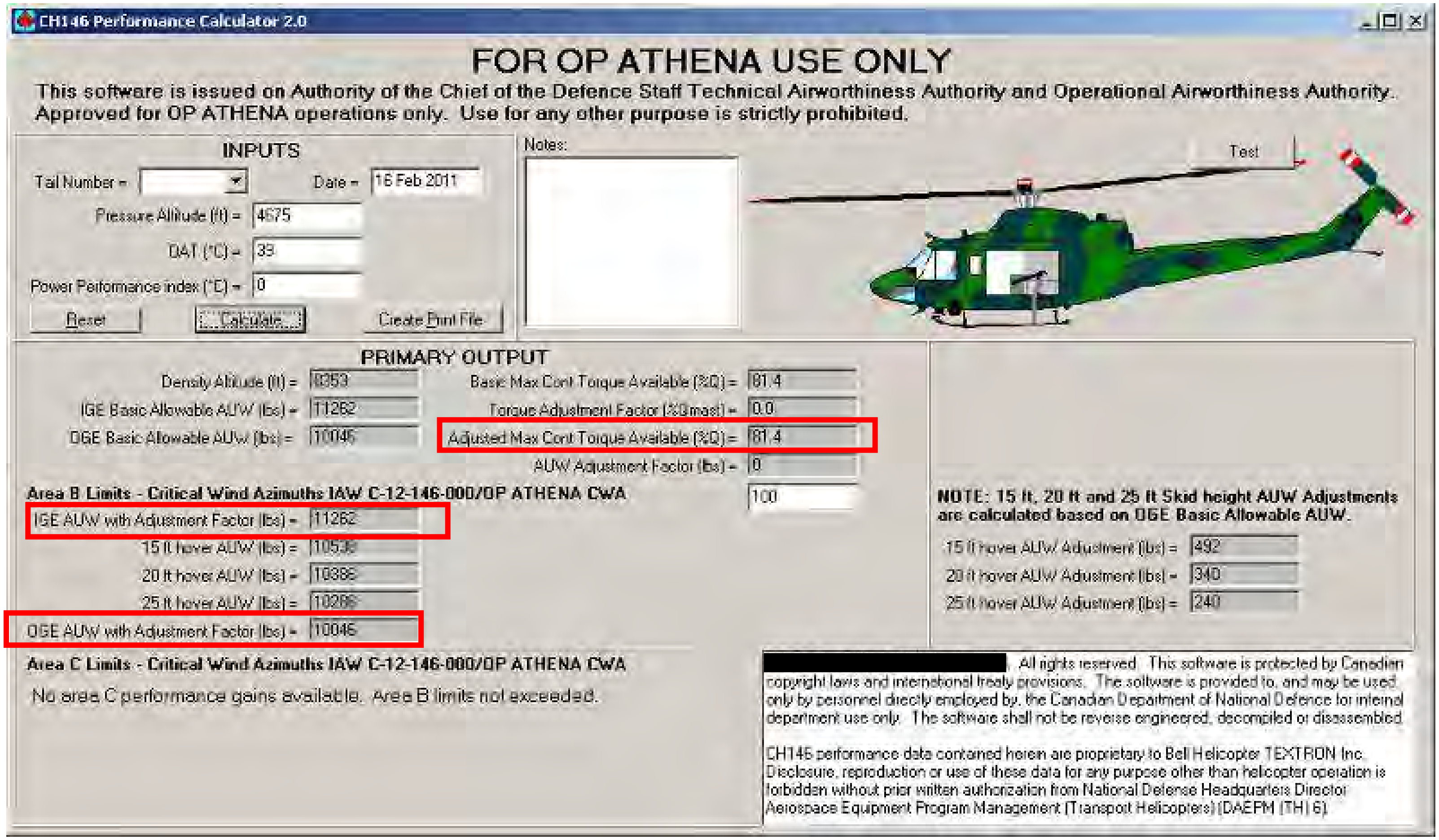


Figure 1 - Software output for a generic CH146 performance for FOB conditions and 0ºC PPI.

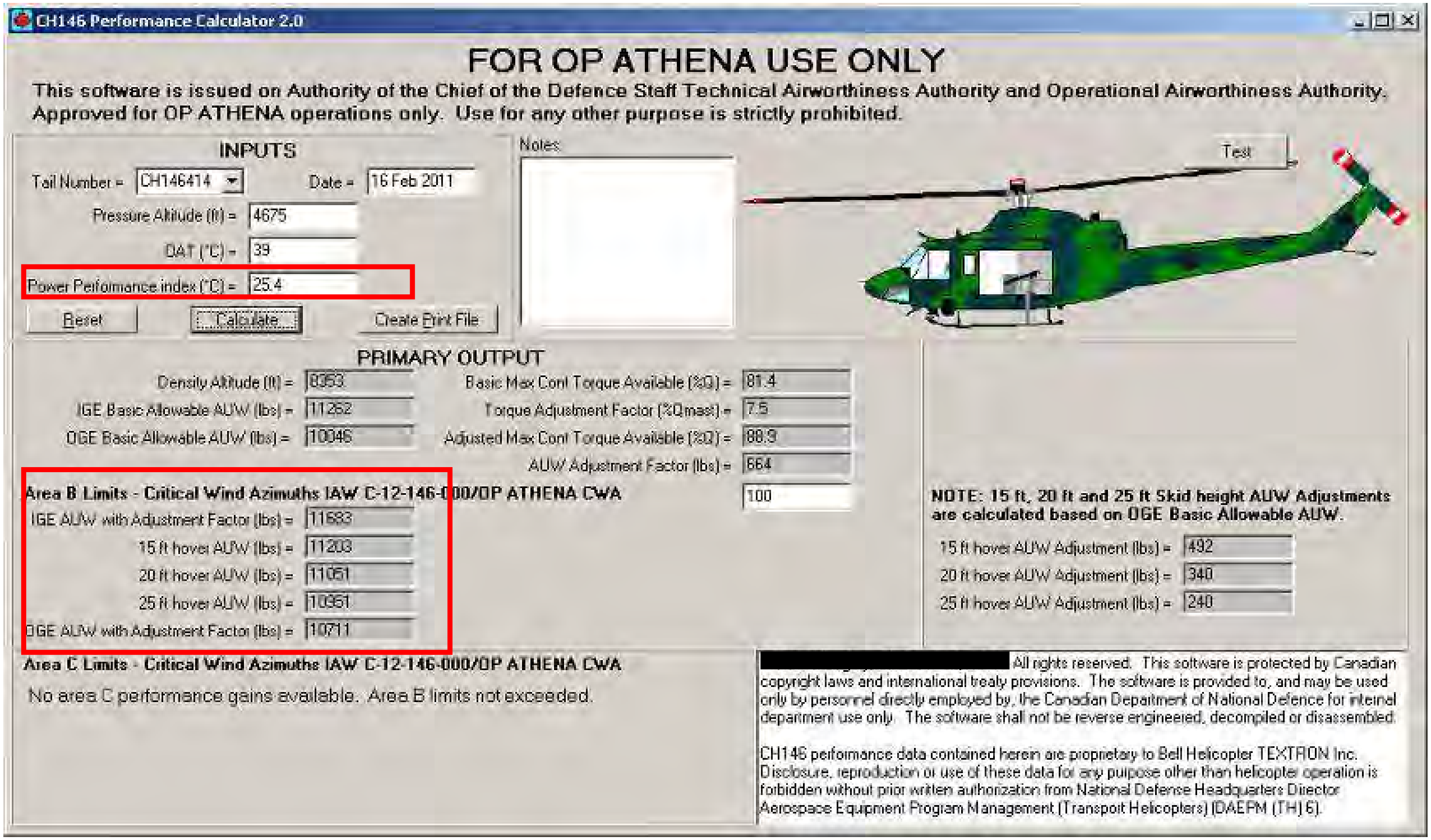


Figure 2 - The #2 aircraft for the afternoon FOB takeoff. This is the best case scenario for the #2 aircraft without exceeding limits. Note baseline PPI of 25.4ºC and various AUWs for OGE and IGE hover heights.

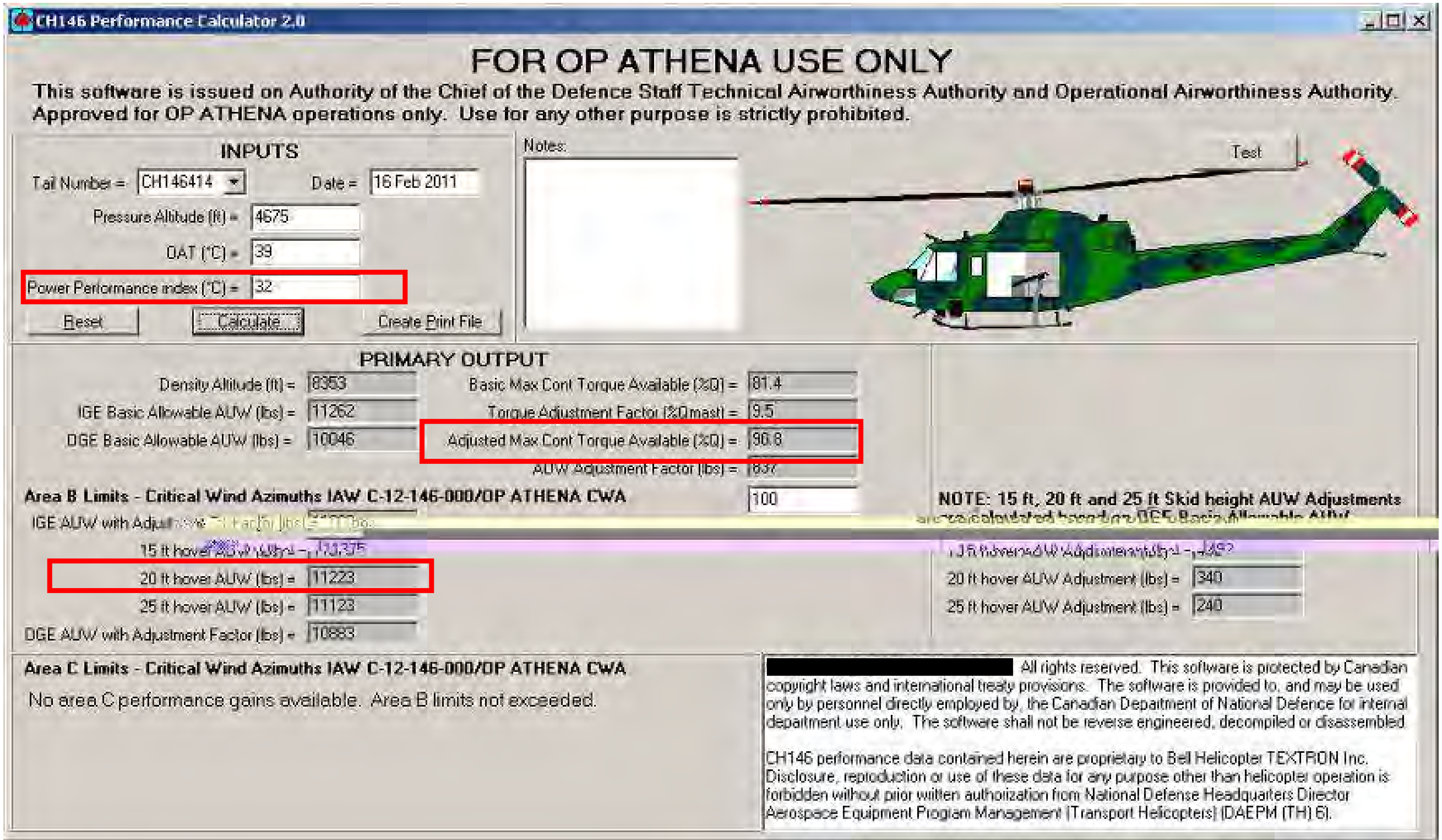


Figure 3 - The #2 aircraft at a 20' hover. Note 90.8 % Qm and 32ºC PPI. Since baseline PPI was 25.4ºC this indicates that they would have seen and ITT exceedences of 6.6ºC to hover at 20'. (32 – 25.4 = 6.6)

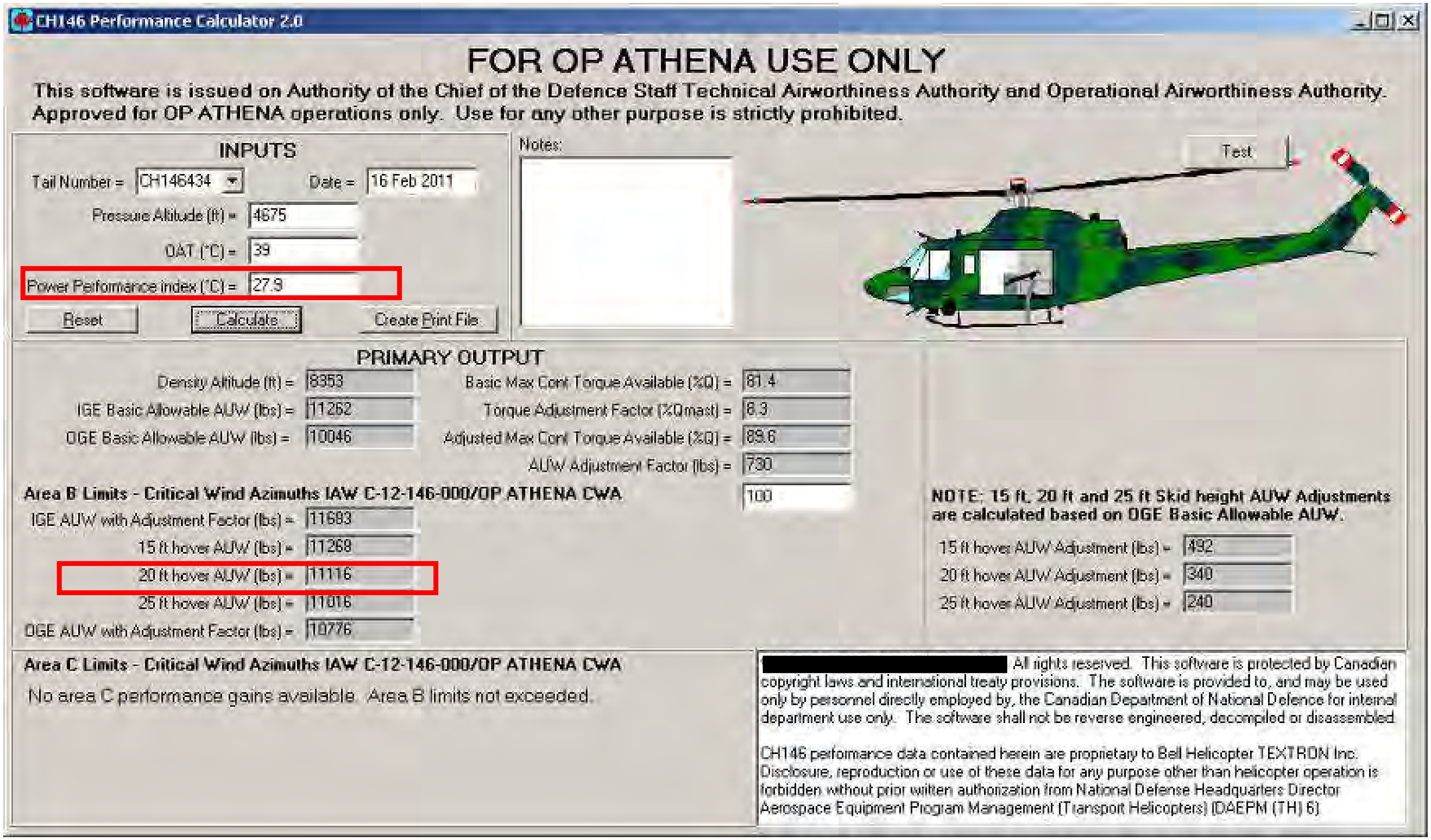


Figure 4 - The accident aircraft for the afternoon FOB takeoff. This is the best case scenario for the accident aircraft without exceeding limits. Note baseline PPI of 27.9ºC.

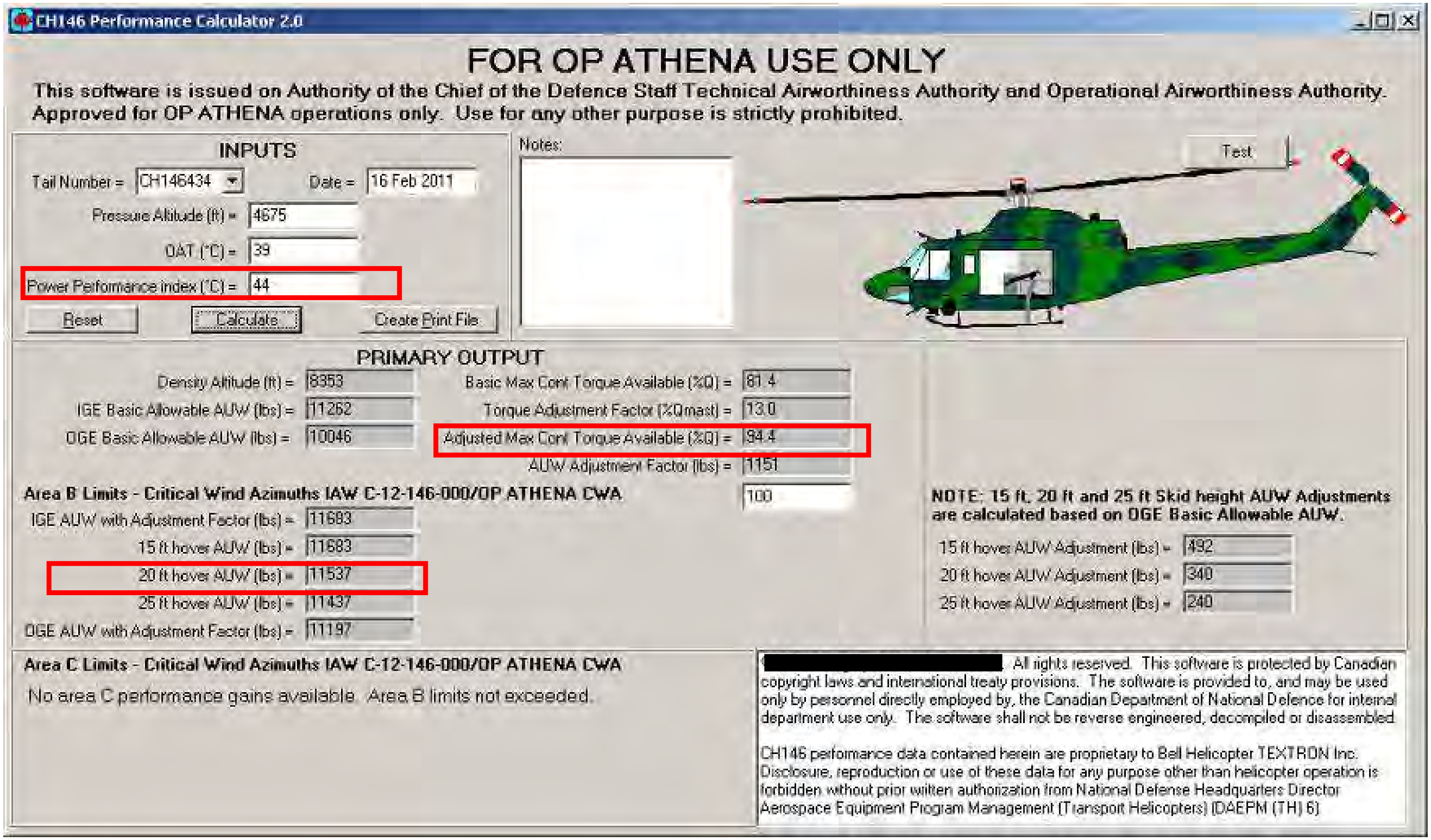


Figure 5 - The accident aircraft at a 20’ hover. Note 94.4 % Qm and 44ºC PPI required for an AUW of 11537lbs. 27.9ºC PPI indicates that they would have seen an ITT exceedence of 16ºC to hover at 20’. (44-27.9=16.1)

“Non-Controlled Goods / Marchandises Non-Contrôlées”

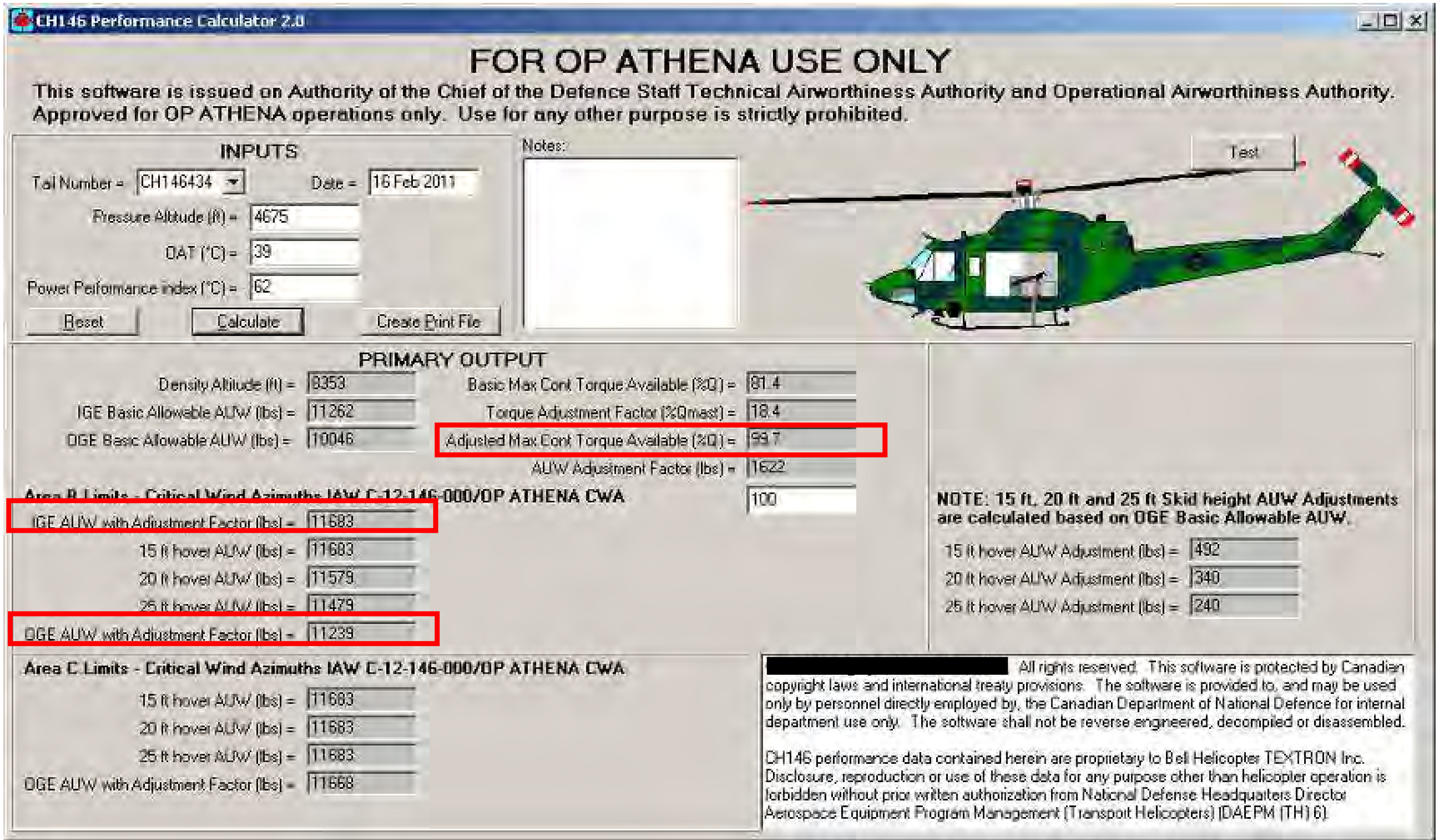


Figure 6 – Shows PPI required to achieve transition assuming a 5% above hover Qm. ITT exceedences of 34.1ºC required for transitions at 99.7% Qm. (62 – 27.9 = 34.1)

Annex L: Abbreviations

1 Cdn Air Div	1 Canadian Air Division
ADI	Attitude Director Indicator
AETE	Aerospace Engineering Test Establishment
AF	Airframe
AFIP	Armed Forces Institute of Pathology
AFM	Aircraft Flight Manual
ALSE	Aviation Life Support Equipment
AOI	Aircraft Operating Instructions
BHS	Basic Helicopter School
BHTCL	Bell Helicopter Textron Canada Limited
C	Celsius
C Air Force	Chief of the Air Force
CAS	Chief of Air Staff
CDS	Chief of Defence Staff
CEFCOM	Canadian Expeditionary Force Command
Ch	Change
CO	Commanding Officer
Comd RCAF	Commander of the Royal Canadian Air Force
COO	Concept of Operation
CF	Canadian Forces
CHF(A)	Canadian Helicopter Force (Afghanistan)
CJOC	Canadian Joint Operations Command
CRH	Crewman Restraint Harnesses
CRR	Crewman Restraint Release
CRT	Crewman Restraint Tether
CSAR	Combat Search and Rescue
CVFDR	Cockpit Voice and Flight Data Recorder
CVR	Cockpit Voice Recorder
DAEPM(TH)	Directorate of Aerospace Equipment Program Management (Transport & Helicopter)
DG	Door Gunner
DGAEPM	Director General Aerospace Equipment Program Management
DRDC	Defence Research and Development Canada
DTA	Directorate of Technical Airworthiness
DTAES	Directorate of Technical Airworthiness and Engineering Support
DVE	Degraded Visual Environment
ETAH	Escadron tactique d’hélicoptères
FAA	Federal Aviation Administration
FAR	FAA Airworthiness Regulations
FDR	Flight Data Recorder
FE	Flight Engineer
FOB	Forward Operating Base

FP	Flying Pilot
ft	Feet/Foot
GFA	Graphical Area Forecast
GW	Gross Weight
HD	Density Altitude
hr(s)	Hour(s)
HIGE	Hover In Ground Effect
HP	Pressure Altitude
HESCO	Hercules Engineering Solutions Consortium
HMD	Helmet Mounted Display
HOGE	Hover Out of Ground Effect
HUD	Heads-Up Display
HUMS	Health and Usage Monitoring System
IETM	Integrated Electronic Technical Manual
IFC	Instrument Flight Condition
IGE	In Ground Effect
IIMC	Inadvertent Instrument Meteorological Condition
IMC	Instrument Meteorological Condition
ITO	Instrument Takeoff
ITT	Inter-Turbine Temperature
JTF(A)	Joint Task Force (Afghanistan)
KAF	Kandahar Airfield
KIAS	Knots Indicated Airspeed
lbs	Pounds
M	Magnetic
MALA	Mission Acceptance, Launch Authorization
METAR	Meteorological Aviation Report
MFS	Maxillo-Facial Shield
Min Spec	Minimum Specifications
MPTO	Maxi Performance Takeoff
N1	Gas Producer RPM
NFP	Non-Flying Pilot
NRC	National Research Council
NVG	Night Vision Goggle
OAA	Operational Airworthiness Authority
OAT	Outside Air Temperature
OEM	Original Equipment Manufacturer
OGE	Out of Ground Effect
OSI	Out of Sequence Inspection
OT&E	Operational Test and Evaluation

PAC	Power Assurance Check
POAC	Provisional Operational Airworthiness Clearances
PWGSC	Public Works and Government Services Canada
Qm	Mast Torque
QETE	Quality Engineering and Test Establishment
RARM	Record of Airworthiness Risk Management
RCAF	Royal Canadian Air Force
ROTO	Rotation
RPM	Revolutions Per Minute
RRPM	Rotor Revolutions Per Minute
SA	Situational Awareness
SDE	Senior Design Engineer
SI	Special Inspection
SMM	Standard Manoeuvre Manual
SOI	Statement of Operating Intent
S/N	Serial Number
TAA	Technical Airworthiness Authority
TAM	Technical Airworthiness Manual
TAWD	Technical Airworthiness Data
TASET	Tactical Aviation Standard and Evaluation Team
Temp Rev	Temporary Revisions
THS	Tactical Helicopter Squadron
TIC	Troops in Contact
VCDS	Vice Chief of Defence Staff
VFC	Visual Flight Condition
VMC	Visual Meteorological Condition
V_{MAX}	Maximum Velocity
V_{MINI}	Minimum Speed for Instrument Flight
VNE	Never Exceed Speed
WAT	Weight-Altitude-Temperature
WComd	Wing Commander
WSM	Weapon System Manager
%	Percent
°	Degree