DRDC Toronto No. CR-2003-125

CONSPICUITY OF THE CH-146 GRIFFON COMBAT SUPPORT HELICOPTER

by:

Tabbeus M. Lamoureux, Paul Stager

Human*systems*, Incorporated
111 Farquhar St., 2nd floor
Guelph, ON N1H 3N4

Project Manager:
Kim Iwasa-Madge
(519) 836 5911

PWGSC Contract No. W7711-017747/001/TOR
Call-Up Nos. 7747-11 & 7747-17

On behalf of
DEPARTMENT OF NATIONAL DEFENCE

as represented by
Defence Research and Development Canada - Toronto
1133 Sheppard Avenue West
Toronto, Ontario, Canada
M3M 3B9

DRDC Scientific Authority
Sharon McFadden
(416) 635-2189

26 August 2003

Abstract

The CH-146 Griffon Combat Support Helicopter operates on Air Weapons Ranges in close proximity to fast-moving fighter aircraft. The Canadian Armed Forces has undertaken to improve the conspicuity of the Griffon by considering alternative lighting and paint schemes. DRDC Toronto was requested to assist in this endeavour and to contract a review of the relevant conspicuity literature. This report documents the review and provides a summarising checklist of factors that should be considered when attempting to enhance conspicuity. A number of conclusions are drawn and some recommendations are made. These recommendations refer to positioning and flash-rate of lights, painting the aircraft light colours on the top and dark colours on the underside, painting discontinuous stripes on the main rotor blades, and the continuing use of procedural range control.

Résumé

L’hélicoptère d’appui au combat Griffon CH-146 s’utilise dans les polygones de tir aérien situés à proximité de chasseurs en déplacement rapide. Les Forces armées canadiennes ont entrepris d’améliorer la perceptibilité du Griffon en examinant diverses configurations en matière de feux et de motifs peints. On a demandé à RDDC Toronto de contribuer à cette recherche et d’octroyer un contrat d’examen de la documentation pertinente sur la perceptibilité. Ce rapport contient des détails sur l’examen effectué et renferme une liste de contrôle résumant les facteurs à considérer pour tenter d’améliorer la perceptibilité. Un certain nombre de conclusions sont tirées, et quelques recommandations sont proposées. Ces recommandations ont trait à la position et à la fréquence de clignotement des feux, à l’utilisation de peintures de couleur claire sur les surfaces dorsales et de couleur foncée sur les surfaces ventrales, à la formation de bandes peintes discontinues sur les pales du rotor principal et à l’utilisation continue du contrôle aux procédures de la distance.

Executive Summary

As part of its on-going use of the CH-146Griffon helicopter, the Canadian Armed Forces are reviewing the rationale for the colour and exterior lighting configuration of its helicopters. In particular, the Canadian Armed Forces are interested in determining the most suitable paint scheme and exterior lighting plus any other measures that might enhance conspicuity of the Griffon helicopter in the combat support role. The primary concern is to ensure that the helicopter is conspicuous to other aircraft such as the CF-18 or other fast moving aircraft that may be using the same airspace. DRDC Toronto was requested to assist in this endeavour by contracting a review of the literature on factors affecting aircraft conspicuity.

After the introduction a description of the method adopted in researching this report, the report is divided into eight sections:

Operational Environment – describes the factors in the operational environment affecting the conspicuity of the CH-146. These include the paint and light schemes of aircraft, the colours in the background (e.g. trees, clouds), the speeds of aircraft, the heights at which they fly, etc. This section is intended as a baseline reference for those seeking to understand the factors affecting conspicuity.

Target Characteristics – describes the features of a target that make it easier or more difficult for the human visual system to detect.

Paint Schemes – describes the scientific and applied literature concerning the use of paint colour and pattern to improve conspicuity.

Lighting Schemes – describes the scientific and applied literature concerning the spatial arrangement of lights, the colour, the flash rate and the duty cycle (ratio of 'on' time to 'off' time) as they relate to conspicuity.

Proximity/Collision Warning Systems – briefly describes safety systems that could potentially be carried aboard aircraft operating in close proximity to each other, and systems already carried by the CH-146 and other Air Weapons Range users that could be exploited to provide inexpensive proximity warning systems.

Other Collision Prevention Schemes – briefly describes methods of reducing the likelihood of near-misses including procedures, communications and time separation.

Summary – presents checklists of the main factors affecting conspicuity. These checklists are intended for use when some change to the appearance of an aircraft is being considered, to ensure that factors affecting conspicuity, and their mutual interaction, are considered in the decision making process.

Conclusions and Recommendations – presents the main conclusions that can be made from this review and makes some recommendations (some of which had already been adopted).

Seven recommendations were made (in no particular order):

- Ensure that white, green or blue strobe lights are mounted in positions that permit observation from as many different viewing angles as possible;

- Ensure that strobe lights flash at a rate of 4 Hz, with a duty cycle between 0.2 and 0.5;
- Ensure that the intensity of the strobe lights is equal to or greater than 40000 cd;
- Ensure that the dorsal surfaces of the aircraft are painted light, reflective colours of sufficient surface area to aid perception by the observer;
- Ensure that the ventral surfaces of the aircraft are painted dark, non-reflective colours of sufficient surface area to aid perception by the observer;
- Paint discontinuous stripes on the main rotor blades in a bright colour;
- Continue the use of procedural range control.

In summary, it is clear that the Air Force has already made positive strides toward improving the conspicuity of the Griffon helicopter, and toward improving safety in general.

Sommaire

Dans le cadre du programme d'utilisation courante de l'hélicoptère Griffon CH-146, les Forces armées canadiennes étudient les configurations de couleurs et de feux extérieurs de leurs hélicoptères. Elles sont particulièrement intéressées à déterminer le motif peint, la disposition des feux extérieurs et tout autre moyen pouvant accroître la perceptibilité de l'hélicoptère Griffon dans son rôle d'appui au combat. Il s'agit principalement de veiller à ce que l'hélicoptère puisse bien se percevoir à partir d'un autre aéronef, par exemple un CF-18 ou tout autre appareil rapide, qui pourrait utiliser le même espace aérien. On a demandé à RDDC Toronto de contribuer à cette recherche et d'octroyer un contrat d'examen de la documentation ayant trait aux facteurs qui influent sur la perceptibilité des aéronefs.

Après une description de la méthode adoptée pour la recherche, le rapport se divise en huit sections:

Environnement d'utilisation – Décrit les facteurs de l'environnement d'utilisation qui influent sur la perceptibilité du CH-146. Ces facteurs comprennent les motifs peints et dispositions des feux des aéronefs, les couleurs de l'arrière-plan (p. ex. arbres et nuages), la vitesse des aéronefs, leur hauteur de vol, etc. Cette section doit servir de référence à ceux qui veulent comprendre les facteurs influant sur la perceptibilité.

Caractéristiques des cibles – Décrit les caractéristiques d'une cible qui facilitent ou compliquent sa détection par le système visuel humain.

Motifs peints – Décrit la documentation scientifique et appliquée concernant l'utilisation des couleurs et motifs de peinture pour améliorer la perceptibilité.

Configurations de feux – Décrit la documentation scientifique et appliquée concernant la configuration spatiale des feux, leur couleur, leur fréquence de clignotement et leur coefficient d'utilisation (rapport de la durée d'allumage à la durée d'extinction) en ce qui a trait à la perceptibilité.

Systèmes avertisseurs de proximité/collision – Décrit brièvement les systèmes de sécurité qui pourraient être transportés à bord d'aéronefs rapprochés les uns des autres ainsi que les systèmes déjà transportés par le CH-146 et d'autres utilisateurs de polygone de tir aérien, auxquels il serait possible de recourir pour constituer des systèmes avertisseurs de sécurité peu coûteux.

Autres moyens de prévention des collisions – Décrit brièvement les méthodes permettant de réduire la probabilité de quasi-collisions, notamment les procédures, communications et espacements temporels pertinents.

Sommaire – Présente des listes de contrôle des principaux facteurs influant sur la perceptibilité. Ces listes pourront servir lorsqu'on envisagera de modifier l'apparence d'un aéronef, afin que les facteurs influant sur la perceptibilité et que leur interaction entrent en ligne de compte dans le processus de prise de décisions.

Conclusions et recommandations – Présente les principales conclusions qu'il est possible de tirer de cet examen et propose certaines recommandations. Quelques-unes des recommandations ont déjà été adoptées pour le Griffon.

Sept recommandations sont indiquées (sans ordre particulier).

- S’assurer que les feux stroboscopiques blancs, verts ou bleus sont montés dans des positions qui permettent l’observation sous autant d’angles différents que possible.
- S’assurer que les feux stroboscopiques clignotent à une fréquence de 4 Hz, selon un coefficient d’utilisation compris entre 0,2 et 0,5.
- S’assurer que l’intensité des feux stroboscopiques est égale ou supérieure à 40 000 cd.
- S’assurer que les surfaces dorsales de l’aéronef sont revêtues d’une peinture réfléchissante de couleur claire, sur une surface suffisante pour favoriser la perception de l’observateur.
- S’assurer que les surfaces ventrales de l’aéronef sont revêtues d’une peinture non réfléchissante de couleur foncée, sur une surface suffisante pour favoriser la perception de l’observateur.
- Peindre des bandes discontinues de couleur brillante sur les pales du rotor principal.
- Continuer le contrôle aux procédures de la distance.

Table of Contents

List of Figures and Tables

1 Introduction

1.1. Background

As part of its on-going use of the Griffon (CH-146) helicopter, the Canadian Air Force (CAF) is reviewing the rationale for the colour and exterior lighting configuration of its helicopters. In particular, CAF is interested in determining the most suitable paint scheme and exterior lighting plus any other measures that might enhance conspicuity of the Griffon helicopter in the combat support role. The primary concern is to ensure that the helicopter is conspicuous to another airborne aircraft such as the CF-18 or other fast moving aircraft that may be using the same airspace. To assist in this endeavour, DRDC Toronto was requested to contract a review of the literature on factors affecting aircraft conspicuity.

The CAF also sought to evaluate an influential study by the RAF (Chappelow and Belyavin, 1992) within a Canadian context. In this study, two Hawk aircraft, one matt black and the other grey, were flown on reciprocal headings to ensure head-on trajectories.

The results of this study indicated that black aircraft were consistently detected earlier than grey aircraft. The authors also calculated that a black paint scheme resulted in a 25% reduction in risk of collision over grey/green camouflage. The black aircraft with the nose light on also had the best detection rate (i.e. number of targets detected in relation to the total number of targets).

While the RAF study is applicable, the CH-146 operates in a more complex environment that may require alternative or additional conspicuity measures. The question is whether there are alternative schemes that can be recommended on the basis of empirical or theoretical information.

In the past, the RAF have attempted to enhance conspicuity by painted training aircraft yellow in 1933, silver and yellow in 1947, dayglow orange in 1958, red and white in 1969 and black in 1993.

The current project has been contracted to Humansystems Incorporated as a call-up under Standing Offer W7711-01-7747/001/TOR. The Scientific Authority (SA) for this work is Mrs Sharon McFadden.

1.2. Purpose

The purpose of this project is to recommend the most suitable colour scheme and lighting configuration, and any other measures that might enhance conspicuity, for the Griffon helicopter in the combat support role.

1.3. Tasks

This work was conducted in two phases:

Phase I

1. Meet with the SA for this work and Subject Matter Experts (SMEs) to determine the operating contexts of the Griffon and the most suitable resources for making recommendations about Griffon conspicuity.
2. Conduct a keyword search for titles and abstracts on the subject of aircraft conspicuity. Evaluate and make recommendations on the appropriate scope of literature that should be obtained for in-depth study.
3. Enter the references uncovered above into an Endnote database.
4. Present a summary of the methods and keywords used to generate the list of articles to the SA. Include in this presentation an indication of the types and comprehensiveness of the information and guidance that can be expected from the review, as well as a shortlist of articles that should be obtained for further review.

Phase II

1. Conduct a more detailed review of the basic and applied research literature concerning factors affecting aircraft conspicuity against different types of backgrounds.
2. Prepare a draft report that provides guidelines for the enhancement of Griffon conspicuity.
3. Review the draft with the SA, revise, and deliver the Final Report.

1.4. Approach Taken in this Report

It is not the intention of this report to make definitive recommendations about how to enhance the conspicuity of the CH-146. The different operating environments for the CH-146 coupled with the variability encountered in viewing conditions make it difficult to establish a single conspicuity measure or benchmark against which modifications to the aircraft can be evaluated. Rather, this report attempts to define the factors that a conspicuity scheme must overcome, and then describes the steps that can be taken to enhance conspicuity. The intent of this approach is to furnish decision-makers with the information required to make informed evaluations of alternative configurations for the CH-146.

In order to provide these data, it was necessary to consider the information at a more abstract level. One can think of the likelihood of a target being detected by the unassisted human observer as determined by three broad factors: the viewing background or contextual environment; the capabilities of the human visual system; and the properties of the target itself (including measures taken to improve conspicuity). This three-way relationship is shown in Figure 1.

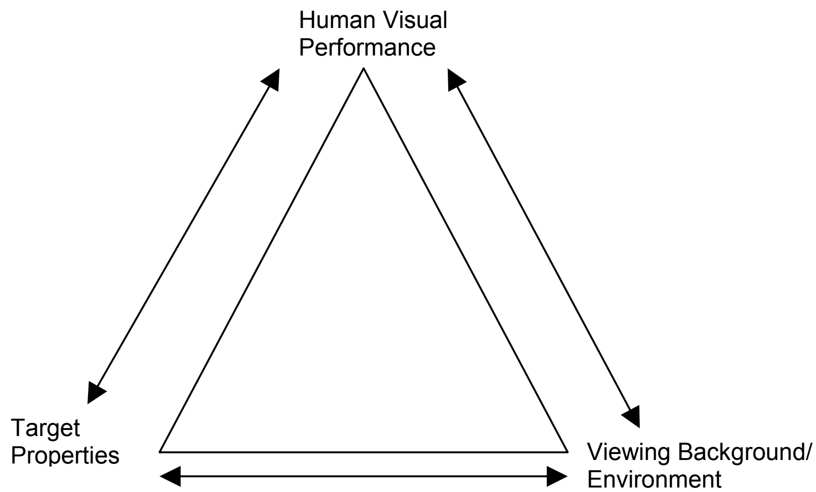

Figure 1: Relationship between factors affecting probability of target detection

All three factors can act independently but are more likely to influence each other. One simple illustration of the relationship is that if the 'values' associated with any one of the three factors is less than optimal, one or both of the other factors must be enhanced to maintain the same probability of detection. For instance, if a target is not very conspicuous, then the human observer will have to have keen eyesight, or else viewing conditions will have to be ideal (or both). Likewise, if the values associated with one factor are exceptionally good, it will render the impact of the other two factors less critical for target detection.

The limitations of the human visual system and the potential for variation in the contextual background have to be taken as givens even though they may not be constant over time. For example, viewing conditions will change from moment-to-moment, day-to-day, and from season-to-season. Thus one has to look at the characteristics of the target (i.e. the CH-146) as the modifiable drivers of conspicuity and detection.

This report first outlines the method followed in compiling the relevant data. It then baselines the operational environment and human visual performance with respect to the factors that cannot be changed. Any efforts to improve conspicuity must overcome the perceptual demands associated with these baselines. The baselines simply describe the conditions within which conspicuity schemes must apply.

This report describes methods of enhancing conspicuity; notably through the use of paint/colour schemes and lights. Data concerning the optimum solutions for conspicuity, as derived from research, are provided. The report also provides a brief reference to the potential for minimising the potential for near-misses that might be achieved with changes to operating procedures and the installation of anticollision systems. It is recognised that the scope of the current work excludes these as options for enhancing conspicuity.

1.5. Acronyms and Abbreviations

ADS-B	Automatic Dependent Surveillance – Broadcast	MAWS	Missile Approach Warning System MCAS Midair Collision Avoidance System
AGL	Above Ground Level	NATO	North Atlantic Treaty Organisation
ARI	Army Research Institute	NISC	National Information Services Corporation
AULIMP	Air University Library Index to Military Periodicals	NTIS	National Technical Information Service
AWR	Air Weapons Range	NVG	Night Vision Goggles
CAD	Canadian Air Division	PWI	Pilot Warning Indicator
CADPAT	Canadian Disruptive Pattern	RAF	Royal Air Force
CAF	Canadian Air Force	RIS	Radar Information Service
CAVU	Ceiling And Visibility Unlimited	RLWR	Radar Laser Warning Receiver
CISTI	Canada Institute for Science and Technical Information	SA	Scientific Authority
CSH	Combat Support Helicopter	SME	Subject Matter Expert
DRDC	Defence Research and Development Canada	TacHel	Tactical Helicopter
DTIC	Defence Technical Information Centre	TCAS	Traffic Collision Avoidance System
EPLARS	Enhanced Position Location Reporting system	TSAS	Tactile Situation Awareness System
HID	High Intensity Discharge	UK	United Kingdom
HUD	Head-Up Display	VMC	Visual Manoeuvring Conditions
IFF	Interrogate – Friend or Foe		

2. Method

2.1. Keywords

Because it is possible that relevant information regarding conspicuity could be contained in a wide range of literature, a large number of search terms were utilised. The table below contains two columns: one entitled 'core concept' and a second entitled ' modifying concept'. Searches of database were conducted by combining a term from the 'core concept' column with a term from the 'modifying concept column'.

Table 1: Search terms used in this work

Core Concept	Modifying Concept
Airborne	"Low Level"
Conspicuity	Warning
Collision	Avoidance
Detection	Pattern
Visibility	Navigation
	Strobe
	Light
	Aircraft
	Helicopter
	Paint
	Scheme
	Fluorescent
	"Fast Jet"
	"Fixed Wing"
	"Rotary Wing"
	System
	Anticollision
	"Visual Contrast"
	"Luminance Contrast"
	"Terminal (Area)"
	TRACON
	Reflectance
	Procedures
	Separation

If a search on any combination yielded particularly high numbers of results, the search would be modified with another term from the 'modifying concept' column.

2.2. Databases

The following literature databases were searched:

- o DTIC – Defence Technical Information Centre
- o NTIS – National Technical Information Service
- o CISTI – Canada Institute for Science and Technical Information
- o ARI – Army Research Institute
- o NISC – National Information Services Corporation
- o AULIMP – Air University Library Index to Military Periodicals

Additionally, the search terms listed above were entered into the Google search engine and a survey of the World Wide Web was undertaken. Also, a search of Flight Safety Occurrence Reports resulted in some relevant incident reports, and three Staff Summaries were obtained from 1 Canadian Air Division (CAD).

2.3. Search

Using the combinations of terms afforded by the lists above, searches of the literature database resulted in a great number of hits. However, after considering the information available for papers matching the search terms, it was often clear that the precise emphasis of a paper was not relevant to improving conspicuity in an air-to-air detection task. For instance, 'detection' would often return papers focusing on fault finding during maintenance tasks. Likewise, 'visibility' would often return papers focusing on a pilot's ability to read instrument displays. In total, 47 references were used in compiling this report. This includes internet discussion threads on military aviation websites, staff summaries and papers provided by the SA. This total does not include Flight Safety Occurrence Reports.

Of the literature provided by the SA, 7 papers focused on lighting, 5 papers on painting, and the remaining 9 papers on general visibility or means to improve target detection/avoidance. The Staff Summaries outline the arguments for and against painting CH-146 in colours affecting conspicuity. They do not include a review of background or literature. Of 26 incident reports, only 6 were near misses between CH-146 aircraft and fast jets. Of these 5 involved CF-18s, all at Cold Lake, and one involved a Harrier, at Goose Bay. Internet threads tended to provide information about what other countries are doing regarding the conspicuity of aircraft.

3. Operational Environment

This section describes the physical appearance of the CH-146 Griffon and the CF-18 Hornet, the backgrounds against which they will be viewed, and other factors that may influence the ease or difficulty with which they are detected. This section is intended to provide information, not to support a particular argument.

3.1. Role and Configuration

3.1.1. CH-146 Griffon

The CH-146 Griffon is deployed in two roles: as a Tactical Helicopter (TacHel) and as a Combat Support Helicopter (CSH). The TacHel is used to support combat operations (i.e. for carrying troops and possibly for combat search and rescue) and is painted in camouflage colours (Figure 2).

Figure 2: CH-146 Griffon TacHel

The CSH used to be called 'Base Rescue Squad' and was painted yellow and red. However, due to the need to rotate equipment from the CSH role to the TacHel role, CSH were painted camouflage colours (the red and white tail rotor paint scheme was retained for reasons of safety on the ground). The CSH is now being returned to the initial paint scheme (Figure 3): predominantly yellow, with a red stripe running diagonally from the engine housing, across the cargo doors and under the belly of the aircraft. The engine housing on top of the fuselage is also painted red, and the nose of the helicopter and the top of the drive-shaft cover are painted black (the nose for anti-glare reasons). Two concentric white stripes of 18" width are painted on each of the main rotor blades (the CH-146 has four blades). Currently, this paint scheme has only been implemented at Goose Bay, but will be rolled out to other CSH units in due course. Both TacHel and CSH carry standard landing, navigation and strobe lights (see Figure 4).

The strobe lights on the CH-146 are positioned on the top and the bottom of the helicopter and flash asynchronously. The strobe lights can be white on the CSH (i.e. have a clear lens cover) but are red on the TacHel (i.e. have a red lens cover). SMEs from both the CH-146 and CF-18 community said that the CH-146 strobe lights are visible. The use of white strobe lights, although an approved configuration, is at the discretion of the Unit or Wing Commander.

Figure 3: CH-146 Griffon CSH from 444 Squadron

The CSH operates only on the Air Weapons Ranges (AWR) at Cold Lake, Bagotville (Valcartier) and Goose Bay. The primary role to which they have been assigned is that of providing a response to fighter ejection on the range, for which they are on one hour standby. Their secondary task is range support that involves transporting technicians and equipment, and placing targets before the range is opened for the CF-18 and other combat aircraft. The CSH may also land to do target maintenance work, a task which SMEs said was made dangerous if the CSH was camouflaged because range users may fire weapons at the target without seeing the CSH. There was no evidence in incident reports reviewed of this happening. The CSH serves in a peacetime training role; it does not provide a combat search and rescue capability.

Figure 4: CH-146 Griffon CSH from 444 Squadron showing landing and navigation lights

The CSH typically flies at 100 – 150 feet above ground level (AGL), although their preferred transit altitude is between 500 and 1500 feet. When transporting equipment, the CSH may carry a sling up to 70 feet beneath the aircraft, and this could place the CSH at a greater altitude than expected.

3.1.2.   CF-18 Hornet and other Fast Jets

The primary threat to a CSH is from the combat aircraft using the AWR ranges. At Cold Lake and Bagotville, the main users are aircraft from the CF-18 Hornet community who will be flying at high speed, at low level, and may be employing ordnance against ground and air targets. The operating base of flight for CF-18s is 500 feet AGL. The range at Cold Lake is instrumented to allow performance assessment. Occasionally, other users such as F-16 or Tornado aircraft, etc. may also be present on the range at Cold Lake.

Most fast jets are painted grey (see Figure 5), although some from other nations are camouflaged. Their colouration, however, becomes a moot consideration given their rate of movement within the AWR range and the limited time that is available for their detection by CSH crew.

Figure 5: CF18 Hornets showing grey colour scheme

NATO (North Atlantic Treaty Organization) aircraft are the main users of the Goose Bay AWR. A mix of aircraft can be found at Goose Bay, including F-16s, Tornados, Jaguars and Harriers. The Goose Bay AWR is not instrumented for bombing practice, however it is used for extremely low-level, high-speed navigation exercises. The base of flight for NATO flights at Goose Bay is 100 feet AGL and this poses even greater danger for CSH operating on the range.

The CF-18 does have radar and will be fitted with IFF (Identify - Friend or Foe) in the near future. It is unlikely, however, that aircraft from the United Kingdom (UK) will be fitted with radar. Other NATO aircraft generally have radar. These systems could be exploited by collision-avoidance systems if such systems are included in a future major mid-life upgrade.

3.2. Above-the-Horizon Background

The AWR ranges at Cold Lake, Bagotville and Goose Bay are used for training in all meteorological conditions and at all times of the day or night. Therefore any effort to make the CSH conspicuous to other air users must accommodate low or nearly zero ambient lighting, CAVU (Ceiling And Visibility Unlimited) conditions, fog, haze and variation in cloud cover as well as in the cloud base.

3.3. Below-the-Horizon Background

The Cold Lake AWR covers an area of 1.17 million hectares straddling the Alberta/Saskatchewan border. The heavily forested terrain with numerous lakes resembles East and North European topography. The terrain is mainly flat, with trees rising to a height of approximately 65 feet. Ground colouration depends upon the covering, which is generally pine trees or lakes (see Figure 6). Inert weapon targets on the range are generally of plywood construction and are built to resemble tanks, missile launchers, aircraft and vehicles. Several mock runways have also been constructed. There are approximately 350 targets positioned throughout the western side of the range.

Figure 6: CF-18 over Cold Lake AWR

The Goose Bay AWR covers approximately 10 million hectares (split between two areas) in Labrador. The terrain is highly wooded and undulating. In addition to the great many lakes, rocky outcrops and cliffs on the west side of the AWR render the overall colouration green with granite grey. For examples of the terrain, see Figure 7 and Figure 8.

No information regarding area was found regarding Bagotville AWR, although it is not believed to be significantly different in terms of its terrain features to Cold Lake and Goose Bay.

Figure 7: Scrub, bog and forest terrain at Goose Bay AWR

Figure 8: River valley terrain at Goose Bay AWR

3.4. Pilot Visual Lookout

During interviews with SMEs, the CSH and TacHel pilots stated that they kept a concerted lookout for fast jets and, when spotted, would attempt to establish radio contact as early as possible (as much for reasons of pride as safety). The CF-18 carries two radios tuned both to their discrete mission frequency and to the common range frequency. Hence, normal communications may cue the CF-18 pilot to search for the CH-146.

Because the CH-146 is operated by a crew they attempt to maintain a lookout for terrain features and other aircraft over a radius of 2 km. Fast jets still pass in close proximity to the CH-146 without being detected, in spite of the diligent lookout. The closing speeds are very high and provide only short reaction times (in the region of 2 seconds). This means that, even if a fast jet is spotted, there is very little manoeuvring the CH-146 can do to avoid the other aircraft. If manoeuvring is possible in the time and space available, the CH-146 pilot will turn to the left and attempt to descend.

During night-time operations CH-146 pilots may use Night-Vision Goggles (NVG). To accommodate the use of NVG, the helicopter strobe lights must be turned off. Further, there is an 'NVG-friendly' setting for the red and green navigation lights. In adverse weather it is also standard procedure to turn the strobe lights off, compounding the problem in terms of detection. The workload in the CH-146 cockpit is very high during NVG operations, in contrast to workload during a routine VFR transit.

SMEs report that the visibility of the CH-146 is assisted at all times by the motion of the rotor (i.e. flicker) and the strobe lights when the helicopter is below the horizon. In general the pilots said they were most likely to detect something in their field of view due to movement. CF-18 pilots thought that painting rotors assisted visibility, as does helicopter movement and associated changes in the viewing angle presented by the helicopter as it moves. The CF-18 SMEs also said that they operate with an expectation that the CH-146 will be lower than their own aircraft, meaning that they are likely restricting their scan area. The angle at which these pilots see another target (relative to the target's motion) will also determine whether it appears to be moving and thus affect the likelihood of detection.

Typically, however, CF-18 SMEs said their scan was limited to just above and just below the horizon. Flying at low level was also considered to add to safety, as it 'sky lights' aircraft at higher altitudes. CF-18 pilots said that in the event of a (head-on) near-miss, they would turn to the right and gain altitude.

CF-18 and CH-146 SMEs noted that their mission plans include information about helicopter operations and their routings to and from their work area. In general, it was thought that procedures, timings and altitude restrictions made flying safe, but that these features were more likely to be applied during exercises rather than during day-to-day operations. It was the perception of the SMEs that most near misses occurred during CH-146 instrument approaches at approximately 15 miles from the airfield on final approach (when the CH-146 is at approximately 3000 feet). It was thought that the normal CF-18 procedure of breaking off overhead the airfield to join and land from a short final approach led to workload and focus of visual attention issues that would make near misses more likely.

The expectation of the observer can significantly affect detection. If a pilot is briefed that a target will be in the area, the pilot will be looking for the target and stands a better chance of detection with the probability of detection increasing as information as to probable location is increased (Edwards and Harris, 1972). Given the workload experienced in modern fighter aircraft at low-level, the expectations of the pilot could be the main determinant between whether a target is detected or missed entirely. Perceptual expectation is a variable that lies outside the mandate of the present report.

3.5. Mid-Air Collisions

There is a wealth of literature on the subject of mid-air collisions. The interested reader is directed to the work of Ends (1967), Hoffmann (1974, 1977), Wickens and Long (1995) and the UK Air Accident Investigation Branch (AAIB: 2000). These various pieces of work have shown that in ideal conditions (i.e. in visibility of approximately 7 miles) uncued detection ranges would be in the region of 30% - 50% of the visibility range. Given speeds of approximately 600 mph (i.e. not a head-on course) it would take a pilot about a mile before being able to change course. Further, it is conceivable that symbology on a Head-Up Display (HUD) can obscure targets or (if the pilot is reading detailed numerical information from the HUD) delay the pilot's appreciation that a target has appeared.

Regan has been active in researching target detection for helicopter pilots (Regan, 1993; Regan and Hong, 1994; Portfors-Yeomans and Regan, 1995; Regan and Vincent, 1995; Kruk and Regan, 1996; Vincent and Regan, 1997). Regan has identified five kinds of difference between an object and its surroundings that can render it visible: luminance, colour, motion, texture and depth. Regan has noted that detection of low – flying helicopters depends to a large extent upon motion parallax (i.e. in which near objects appear to move across the visual scene more quickly than more distant objects) and textural differences between the helicopter and its background. The technical issues surrounding the representation of texture and object dynamics in a simulator have meant that training target detection in the simulator has been met with limited success.

3.6. Previous Efforts to Improve CH-146 Griffon Conspicuity

Three staff summaries have been written concerning the conspicuity of the CH-146 Griffon CSH (Meinzinger, 1999; Hunter, 2002; Charpentier, 2002). Meinzinger addresses the issue of painting the CSH yellow and noted that inter-fleet transfers (between the CSH and TacHel squadrons) are becoming less frequent and therefore less of a concern for decisions about colour.

Hunter reviewed the CH-146 incident data and concluded that there is no data to indicate that a given paint scheme either contributes to or detracts from safety. He noted that procedures, prevailing weather and light conditions made detection difficult above 2 miles and that the key to reducing incidents was effective procedures and better radar coverage. Hunter considered three options: no change, painting the CSH yellow, and painting the CSH cargo doors yellow and the rotors some other high visibility colour. The last option was considered best on the basis of air-to-air visibility, air-to-ground visibility, operational flexibility and cost.

Charpentier concluded the issue by reporting that the rotors would be painted with three stripes (based on a local trial) and that strobes had been installed. The current approach following from the Charpentier report has been described in Section 3.1.1 and illustrated in Figure 3. Charpentier noted that there had been no near misses since the installation of the strobes, but also commented that a solution involving procedures for the AWR was likely to be best. In contrast to Hunter, Charpentier found two flight safety reports (both filed by 417 Squadron, Cold Lake) that implicated the paint scheme as a safety factor. A risk assessment categorised the contribution of the paint scheme to the risk of collision as medium to low.

All near miss reports involving the CH-146 in the flight safety database were reviewed. Of the 26 incident reports involving the CH-146, only 6 were near misses between CH-146 and combat aircraft. Of these 6, 5 involved CF-18, all at Cold Lake, and one involved a Harrier at Goose Bay. Only one of these incidents occurred on approach. In three cases the CH-146 made avoiding actions; in all cases the combat pilot did not see the CH-146. Procedures can be implicated in 5 incidents (flying over closed targets or in closed areas). In 4 cases, the CH-146 was at low-level (i.e. less than 100') or lifting off (and thus below 100'). In all incidents, conditions were good VMC. Given the descriptions associated with each report, it is difficult to determine if the Griffon camouflage paint scheme would have represented a threat to safety.

THIS PAGE LEFT BLANK INTENTIONALLY

4. Target Characteristics

This section summarises the psychophysical literature regarding generic properties of a target and the impact that mitigating factors have on the likelihood of detection of that target. The interested reader is directed to Boff and Lincoln (1988) in the first instance for further detail.

Regan's (1997) description of the five kinds of difference between an object and its surroundings that can render it visible: luminance, colour, motion, texture and depth was presented above in Section 3.5.

Luminance is the intensity of the light reflected or emitted by the target. Obviously if the luminance of the target is sufficiently different to that of the background, then the target will stand out from the background. The difference in luminance between a target and its background is also called 'contrast'.

Colour is closely related to luminance in the sense that different colours are likely to reflect differential amounts of light (different colours can also reflect the same amount of light). The decision by the UK Royal Air Force (RAF) to paint training aircraft black exploits this feature as black reflects little light while the daytime sky is generally comprised of light colours. This will render them more difficult to discriminate in lower light levels or under adverse viewing conditions. The difference in colours that makes one discernible from another is also called contrast (note: for the remainder of this report, 'contrast' will refer to luminance contrast).

It is likely that a successful conspicuity scheme is going to exploit more than one of luminance, colour, motion, texture and depth. Movement is of great assistance to a pilot in detecting low-flying helicopters. Helicopters are unique in that they can be stationary in the air (unlike fixed-wing aircraft) which can put them in danger. To be conspicuous, targets should attempt to maintain the appearance of movement, even when stationary. Fortunately for helicopters, the main and tail rotors will still be turning if the helicopter is in the air, and it is possible to exploit their rotation to give the impression of movement (via flicker) from a number of different viewing angles, even when the helicopter is stationary.

Texture is also important for detection of low-flying targets with the 'broken' texture of ground or trees representing a significant textural difference to a helicopter painted a single colour (CADPAT (Canadian Disruptive Pattern) camouflage patterns would seem to exploit this perceptual feature). The impact of textural differences will be mitigated by colour and luminance similarities, so it is important that if a helicopter is painted a single colour, it should be distinct from the likely background. If conspicuity is to be enhanced by painting portions of an aircraft different colours it is worth noting that in many contexts blocks of colour must be of sufficient size before they are perceived.

The depth at which the target appears in the overall scene (i.e. the distance from the observer) acts in concert with motion to produce the phenomenon of motion parallax. An object that does not stand out due to differences in luminance, colour or texture is likely to be detected through parallax. The perception that a target is moving by the observer at a different rate to the background can make the target stand out.

The required contrast between a target and its background should also be considered. A minimum contrast ratio of 3:1 should be met, but that contrast ratio is only satisfactory for relatively slow-paced tasks. Contrasts should be much higher for tasks where rapid and accurate perception is important. Under these conditions, a contrast ratio of 20:1 or more is frequently recommended. Studies (Crook, Hanson and Weisz, 1954; Howell and Kraft, 1959; Snyder and Maddox, 1978) have shown that visual performance increases with improved contrast over a range of contrast ratios from 2:1 to 40:1. The inference is that if a person can perform faster with a higher contrast image, it is because that image is easier to see.

5. Paint Schemes

As noted above, the paint scheme adopted for an aircraft will greatly influence the likelihood of its detection. The following sections briefly report previous efforts to use paint schemes to address the issue of conspicuity.

5.1. Colours

Hoffmann and Buell (1974) studied the effectiveness of paint schemes against an alpine background (i.e. surface and sky) that approximates to the ground cover and sky at Cold Lake and Goose Bay. They found that dark green aircraft were detected against the sky more consistently and earlier than yellow-red aircraft. There was no apparent difference in detection rates or ranges between the dark green and yellow-red aircraft against the wooded mountains.

In common with Chappelow and Belyavin, 1992), Hodgson (1959) found that black was very conspicuous against the sky. Hodgson also determined that fluorescent colours were more conspicuous at greater ranges than the equivalent, non-fluorescent, colour. Although the fluorescent paint did not result in significantly higher contrast ratios with the background than did conventional paint, it was noted that fluorescent paint was ‘unnatural’ in nature and so might be more easily detected. Other studies have also noted an advantage for fluorescent paints (e.g. Blackwell, 1960; APC, 1961; APC, 1962), and one study in particular (Siegal and Crain, 1960) noted that fluorescent blue holds a performance advantage over other colours in peripheral vision.

The advantage of fluorescent colours for detection may act in concert with appropriate briefings. Schieber (2002) found that fluorescent targets were not detected any quicker than regular targets. However, once observers had the expectation that the target would be fluorescent, detection times improved. This could have implications for pilot briefings.

5.2. Patterns

In his 1959 work, Hodgson recommended that fluorescent paint should be used in reasonably-sized blocks (not simply bands of colour) to enhance detection ranges. This view has support from studies in the marine environment (Miligan and Tennant, 1997).

Wagner and Blasdell (1948) looked at 37 different paint patterns involving red-orange fluorescent paint against a variety of backgrounds. They concluded that, in general, aircraft should be painted with light, reflective colours on the top, dark, non-reflective colours on the bottom, and an unnatural colour on the rear portion of the aircraft including the tail, stabilisers and rudder. This approach (with the exception of the recommendation about the tail) was also put forward by the Police Aviation News (2001).

Head (2000) studied the conspicuity of gliders. He painted dayglow strips on the leading edge of the wings in two blocks of four. The addition of these patches of colour, in this configuration did not lead to any improvement in detection. Indeed, observers commented that detection was mainly through movement (slight turn or wing levelling), a glint of light or detecting the silhouette against the sky. Hodgson’s recommendation about painting reasonably-sized blocks of colour corresponds to the findings about the patches of colour. Chappelow, Belyavin and Smith (1993) take this further by suggesting that breaking up the outline of an aircraft by painting it in different colours or adding strips may actually make an aircraft more difficult to detect.

5.3. Mitigating Factors

Two important points should be made about the Chappelow and Belyavin (1992) study that are relevant to the conspicuity of the CSH: the study reported the findings of an air-to-air detection task; and pilots always knew where the other aircraft would appear. In the case of the CSH, fast jet pilots will most likely be looking air-to-ground for the helicopter and they will not know where the helicopter (or any target for that matter) will appear. The difference in background luminance and colour, and the expectations of the pilots, between this study and operational training on an AWR may render the conclusions of this study less applicable to the CSH.

One other point should be made about the use of patterns and colours to enhance conspicuity. To see a target's colour or a pattern, there must be sufficient light to illuminate the target. In cloudy and overcast conditions, or at dusk or at night, there may not be enough light to illuminate the target and thus provide contrast between colours or patterns and their background. A conspicuity solution that addresses the most situations is likely to involve lighting as well as paint.

6. Lighting Schemes

One consideration in using colour or blocks of colour to enhance detection is that the potential contribution to conspicuity is restricted to higher ambient light conditions. At dusk or in night-time operations (and frequently in heavy overcast conditions) detection will depend more on aircraft lighting rather than on a particular paint scheme. It has long been thought that a powered light is the best method of enhancing daylight as well as low-light level target detection (Chisum, 1977). A powered light will almost invariably emit more light than is reflected from some surface in natural lighting conditions and increase the potential detection range. The sections below summarise the research concerning how to make lighting conspicuous.

6.1. Flash Rate and Duty Cycle

There has been a great deal of work on determining whether conspicuity is greater with steady or flashing lights and on the most effective flash rates. Conspicuity has been shown to be greater with flashing lights whether in daylight viewing conditions or night (e.g. Smith and Goodwin, 1971; Connors, 1975b; Mandler, 1989; Thackray and Touchstone, 1991). There are two variables that pertain to flashing or blinking lights. These are the rate or frequency of the flashes and the duty cycle of the on-off state. Both variables are addressed in the following paragraphs.

6.1.1. Flash Rate

Early research into flash rate (e.g. Crumley and Atkinson, 1954) concluded that high flash rates were more effective in enhancing conspicuity. This conclusion has been refined to the point where most studies routinely conclude that a flash rate of 4 Hz maximises detection (e.g. Wagner and Laxar, 1996; Gerathewohl, 1953, 1954, 1957; Laxar and Luria, 1993; Laxar and Benoit, 1993; Smith and Goodwin, 1971). However, Katchmar and Azrin, 1956; Markowitz, 1971 have found that flash rates of up to 10 Hz are more conspicuous. It should be noted, however, that flash rate will interact with colour, size of the light, its intensity, configuration and duty cycle.

6.1.2. Duty Cycle

The duty cycle of a light is defined as the amount of time a light is on as a proportion of the total time required for the light to be on and off. A duty cycle of 0.2 would mean that the light is on for one-fifth of the cycle and 0.5 for half of the time. Several studies have investigated this variable in the context of particular applications. Although the recommended duty cycle will vary slightly in accordance to the flash rate, most studies have concluded that duty cycles from 0.2 (e.g. Gerathewohl, 1953; Markowitz, 1971; Mandler, 1989; Laxar and Luria, 1993; Laxar and Benoit, 1993) to 0.5 (e.g. Gerathewohl, 1954; Smith and Goodwin, 1971; Markowitz, 1971; Connors, 1975; Laxar and Benoit, 1993) are optimum.

Flash rates and duty cycles can inadvertently be set too high or too low for particular task environments. For instance, longer duty cycles may appear as steady lights to an observer engaged in a continuous broad scan for possible targets. Equally, lower flash rates can be seen as steady lights. Although higher flash rates and shorter duty cycles seem to be best for conspicuity, taking this approach to extremes may result in the observer missing the light in the course or a broad scan. That is, other tasks being conducted by the potential observer may be such that the time allocated to the visual sampling or scanning of the observer's environment renders a particular flash rate or duty cycle less effective than intended.

6.2. Configuration

Less work has been done looking at the configuration (spatial arrangement) of lights, presumably because this factor depends more than most on the viewing angle. Gartner and Pudsey (1965) investigated the placement of lights on fixed wing aircraft at the wing tips, on the tail, and on the top and bottom of the fuselage. In general, none of the lights were detected before the aircraft itself. No other evidence to support particular recommendations for lighting configurations in the AWR application was located in the preparation of this report.

6.3. Colour and Intensity

6.3.1. Colour

Lighting is intended to alert pilots to the presence of another aircraft and not necessarily to convey information. However, very little work seems to have been done on the varying effectiveness of different colours other than white for alerting purposes. Connors (1975b) looked at red, yellow, white, green and blue lights from this perspective. Red lights were the most frequently missed and yielded the slowest response times while blue lights were detected most consistently and exhibited the fastest reaction time. This finding corresponds with findings by Siegel and Crain (1960) and Costanza, Stacey and Snyder (1980). Unfortunately, neither study reported the photometric characteristics of the lights used in the two studies.

6.3.2. Intensity

Light intensity is therefore the most likely method of improving conspicuity (rather than colour). Chisum (1977) stated that an intense light of 70 – 105 cd[1] would render a target visible in CAVU conditions at ranges far in excess of the point where the aircraft becomes too small to see. Lights of more than 40000 cd and a spread of ±40° in azimuth (e.g. Xenon High Intensity Discharge (HID) lamps) are possible (Chappelow and Belyavin, 1992), so contrast sensitivity and visual acuity in bright conditions should not be an issue. Further, the spread of the light should enable an all-round field of view to be maintained.

[1] Candela – the measurement of light intensity over an area of one square centimetre ($1cm^2$).

6.4. Mitigating Factors

In addition to the points made above, Chisum (1977) notes that, in conditions of intense ambient lighting, aircraft lighting can effectively blot out the aircraft itself and bleed into the background, leaving the aircraft effectively invisible. This view finds supporting evidence from Milligan and Tennant (1997) who found the same effect when using lights to improve the conspicuity of personal watercraft. To combat this, lights must be sufficiently brighter than the background in order that they are detectable.

THIS PAGE LEFT BLANK INTENTIONALLY

7. Proximity/Collision Warning Systems

This section is not intended to provide a detailed discussion of proximity/collision warning systems that exist or could be implemented on the CH-146 or CF-18. For the purposes of this report, this section serves to balance the options regarding enhancing conspicuity by reminding the reader that there are options other than paint and lighting schemes.

Information was received from 1CAD regarding systems that emit and receive signals outside the aircraft that could be exploited by future proximity/collision warning systems. These systems were:

- Transponder Mode 1 – nonsecure method of providing positional information;
- Transponder Mode 2 – nonsecure method of providing enhanced positional information;
- Transponder Mode 3A – standard, nonsecure, method used by commercial aircraft to relay positional information to ground stations (i.e. civilian air traffic control);
- Transponder Mode 3C – standard, nonsecure, method used by commercial aircraft to relay altitude information to ground stations (i.e. civilian air traffic control);
- Transponder Mode 4 – secure, encrypted, IFF;
- Missile Approach Warning System (MAWS) receiver - AAR 47;
- Radar Laser Warning Receiver (RLWR) - SPS-65;
- Doppler Radar - used for navigation;
- Radar Altimeter.

The systems listed above may be leveraged to allow the implementation of the following proximity/collision warning systems :

- TCAS – Traffic Collision Avoidance System: widely used in civilian airliners, current version uses transponder Mode S so would require further modifications to CH-146 and/or CF-18. Also, available real estate in a fast jet cockpit for a TCAS box is limited and current TCAS implementation is inhibited below 700'. The C-130J is equipped with E-TCAS which does work at low level, and displays all 7001 codes. Additionally, E-TCAS can display up to 10 codes (at user's discretion) and displays the warning on the navigation/radar displays and on the HUD. Alternatively, a TCAS implementation could be made with low level audible alerts for traffic advisories and louder audible alerts for resolution advisories. The inhibit function could also be disabled unless the aircraft wheels were down (to minimise traffic alerts on approach) although this would be less useful for the CH-146.
- EPLARS – Enhanced Position Location Reporting System: typically fielded with ground forces, EPLARS provides position location identification and navigation services to users. EPLARS position location reports are provided to

automated systems in command and control centres for maintaining near real-time situation awareness displays. Again, this represents a new technology to the aircraft in question, although this means that any implementation can be adapted to optimally 'fit' the pilot's task requirements.

- MCAS – Midair Collision Avoidance System: involves an audible/visual warning then an automatic breakaway upon determination of an impact with another aircraft in non-formation flight (Allen et al, 2000). This system relies on data link systems to share encrypted information between aircraft.
- PWI – Pilot Warning Indicators: refers to presenting on the HUD information regarding other aircraft in the area. By cueing the pilot regarding where to look the probability of target detection is significantly improved.
- TSAS – Tactile Situation Awareness System: the components of this system are the sensors, information processing capability, tactors (buzzers) and tactor locating system. These components act to orient the pilot through touch. Although originally envisaged to increase situation awareness in order to reduce mishaps through collision with the ground or out of control flight, this technology could be used to reduce the amount of information being presented via the HUD (Allen et al, 2001).

Other proximity/collision warning systems are possible using the variety of data link reporting systems being fielded (e.g. ADS-B (Automatic Dependent Surveillance – Broadcast); Mode S) although in all cases (including those listed above) there would be a substantial cost associated with the implementation.

7.1. Mitigating Factors

As noted above, the cost of installing automated proximity/collision warning systems is likely to be high. It is probable that a cost-benefit assessment of the risk of collision, the cost of incidents, and the cost of a proximity/collision avoidance system would determine that installing these systems is not cost-effective. This does not mean that these systems should not form requirements in future aircraft procured for the Air Force.

One other limitation of the proximity/collision warning systems is that both aircraft (in a pairing) must be equipped with the required emitters and receivers. Given that Goose Bay is mainly used by foreign Air Forces for navigation training, it is possible that they will not have systems that can be used by the CSH for traffic avoidance. This might render such expense redundant.

8. Other Collision Prevention Schemes

Most other collision prevention schemes will involve some form of procedure that pilots must follow. Indeed, many attempts to date to eliminate near-misses or collisions have focused on procedures. Procedures that have been tried, implemented or suggested include:

- AWR reporting points – where aircraft must hold before receiving permission to enter the range;
- Target area closures – zones around targets that are closed to allow the CSH crews to conduct maintenance work;
- Pilot briefings – that inform pilots of the likelihood, location and physical appearance of other range users;
- Time separation of range maintenance activities and operational training;
- Dedicated helicopter routes – sterilising a route and a block of altitude for the safe transit of helicopters to and from their destination;
- Tactical altitude flight – requiring helicopters to fly at 15' above ground level (well below the minimum altitude for aircraft at Goose Bay, but difficult when carrying a slung load);
- Standard Approach Routes - for all aircraft approaching the aerodrome unless requested and approved by the approach controller.

Another possibility for reducing near misses on the AWRs is the provision of a situation display for the range controller. Since all aircraft monitor the common range frequency, the range controller could use the situation display to provide traffic information, in common with a Radar Information Service (RIS). This would not require the provision of vectors for avoidance, merely the range and bearing of traffic. Additionally, the range controller would have ability to monitor when and which flights violate restricted zones. Such violations could result in penalties that would encourage pilots to be more diligent in observing restricted zones.

Costanza, Stacey and Snyder (1980) put forward four possible means of improving air-to-air target acquisition: training, selection, cueing, and optical aides (e.g. image intensifiers, binoculars). They concluded that training, selection and cueing could lead to improvements, but that there was no evidence that optical aides improved performance to such an extent that they outweighed the negative issues associated with them (e.g. practicality, workload, etc.).

8.1. Mitigating Factors

Most schemes require a dedicated, real-time range controller to maintain an awareness of who is on the range and where, and thereby issue clearances to aircraft waiting to enter the range. This is likely to have an adverse impact on the training of fast jet pilots, who are likely to have limited fuel for holding operations. A range controller can operate without a situation display, but is likely to be much more responsive with a situation display. Whether this situation display is provided through extrapolation from the instrumented range or via radar, this will add substantial cost to solving the issue of mid-air collisions and near misses.

Additionally, the notion of ‘penalties’ for violating restricted area could be extremely contentious, and would need to be approached with caution.

9. Summary

This section summarises the main points made in this report. The summary is in the form of a flowchart/checklist to ensure that future decisions regarding enhancements to aircraft conspicuity consider the main variables involved. It should be remembered that these points are for general guidance, and operational, practical or cost-benefit reasons may require some of these guidelines to be contravened. Also, many variables may influence others. This interaction may detract from the anticipated conspicuity of a chosen scheme, so careful consideration of each variable should be made.

9.1. General

Guideline	Yes	No	Comment
Is the target large enough to be seen without specific conspicuity measures?	☐	☐	If 'Yes' then additional conspicuity measures may be unnecessary.
Will the target be moving?	☐	☐	Depending upon viewing angles, moving objects may appear stationary. It may be possible to create the impression of movement (or a change in the environment) by using flashing lights or painting rotors.
Is the luminance of the target sufficiently high or low to be apparent against its background?	☐	☐	Applicable to both paint and light schemes.
Is the colour of the target sufficiently different to its background to be discriminated?	☐	☐	Applicable to both paint and light schemes.
Is the contrast ratio of target to background at least 20:1?	☐	☐	Applicable to both paint and light schemes.
Is the apparent texture of the target sufficiently different to be apparent against its background?	☐	☐	Differences in texture can create a 'hole' in the background that can aid detection.
Has the appearance and probable location of the target been briefed?	☐	☐	Target cueing will enhance target detection.

9.2. Paint Schemes

Guideline	Yes	No	Comment
Will the target predominantly be viewed in daylight conditions (i.e. good light)?	☐	☐	If ‘No’, conspicuity will only be aided through lighting.
Is the colour chosen ‘unnatural’ in the environment (e.g. fluorescent colours, especially blue)?	☐	☐	No applicable comment.
Are the significant colours presented in sufficiently large blocks to be perceived at distance?	☐	☐	Smaller blocks of colour, or arrangements of different colours can interact to reduce conspicuity.
Are the dorsal surfaces of the aircraft painted in a light, reflective colour?	☐	☐	Light colours are most likely to provide adequate contrast with AWR ground colours.
Are the ventral and lateral surfaces of the aircraft painted in a dark, non-reflective colour?	☐	☐	Dark colours are most likely to provided adequate contrast with sky conditions.

9.3. Lighting

Guideline	Yes	No	Comment
Is the flash rate of the lights approximately 4 Hz?	☐	☐	No applicable comment.
Is the duty cycle of the lights between 0.2 and 0.5?	☐	☐	No applicable comment.
Is the colour of the lights blue, green or white?	☐	☐	No applicable comment.
Are the lights intense enough to be distinct in a sky with bright ambient light?	☐	☐	No applicable comment.
Are the lights positioned so as to be observable regardless of the attitude of the aircraft?	☐	☐	No applicable comment.
Are the intensity and location of the lights such that the aircraft will be rendered invisible?	☐	☐	No applicable comment.

10. Conclusions and Recommendations

10.1. Conclusions

Conspicuity is a complicated interaction between luminance, colour, motion, texture and depth. These factors are themselves influenced by the size of the target, the viewing distance and the length of time a target is visible. A scheme to enhance conspicuity needs to address these latter issues through some combination of the five listed factors.

Based on a consideration of the characteristics of the operational environment and the aircraft active therein, it is unlikely that any attempt to enhance conspicuity will optimally match requirements across the range of possible issues. The most effective solution will strike a balance between unequivocal conspicuity and applicability to different contexts. For aircraft, the best balance is struck by painting the dorsal surfaces of the aircraft a light, reflective colour and the ventral surfaces a dark, non-reflective colour.

As noted in section 3.1.1, the CSH is currently painted yellow with a red stripe over the cargo doors and continuing underneath the aircraft. The use of yellow seems to fall between the light colours prevalent with a sky background and the darker colours of the terrain background. The red engine housing, black nose and black drive shaft cover may, however, compromise the conspicuity benefits of yellow if the observer was to view the helicopter from above by reducing contrast and breaking up colours.

The CSH also has two concentric stripes on each of its four main rotor blades. These will create a circular flickering effect that, depending upon the rotations per minute, will slowly revolve around the fuselage of the helicopter. The detectability of the flickering stripes may be enhanced if the stripes were discontinuous from one rotor blade to another (i.e. the stripes appear in different positions along the blade). The CSH also has white strobe lights mounted on the top and bottom of the fuselage. These are likely to aid conspicuity in all conditions.

Overall, the changes recently made to the colour scheme of the CH-146 Griffon helicopter will enhance its conspicuity. Further, the use of high-intensity strobe lights with the revised colours represents a pragmatic solution to the problem of conspicuity against an extremely variable background.

The AWRs are subject to a number of procedures, from the provision of pre-flight briefings to the use of a common range radio frequency. Procedures are considered by SMEs to be effective at maintaining safety on the ranges. Given the number of near misses in which the CSH has been involved, it is likely that a cost-benefit assessment will determine that any measures to address near-misses beyond those employing procedures, lighting or paint will not provide an adequate return on investment.

10.2. Recommendations

Although the changes made recently improve conspicuity, to further enhance the conspicuity of the CH-146 Griffon helicopter in the CSH role and minimise the likelihood of near-misses with other AWR users, the following recommendations are made (in no particular order):

- Ensure that white, green or blue strobe lights are mounted in positions that permit observation from as many different viewing angles as possible;
- Ensure that strobe lights flash at a rate of 4 Hz, with a duty cycle between 0.2 and 0.5;
- Ensure that the intensity of the strobe lights is equal to or greater than 40000 cd;
- Ensure that the dorsal surfaces of the aircraft are painted light, reflective colours of sufficient surface area to aid perception by the observer;
- Ensure that the ventral surfaces of the aircraft are painted dark, non-reflective colours of sufficient surface area to aid perception by the observer;
- Paint discontinuous stripes on the main rotor blades in a bright colour;
- Continue the use of procedural range control.

11. References

(2001). Conspicuity - a Winner or Loser? Police Aviation News: 3-4.

Air_Accidents_Investigation_Branch, U. K. (2000). Aircraft Accident Report No. 3/2000, Appendix D: Estimation of Detectability of Each Aircraft Involved in the Collision.

Allen, T. L., K. M. Eveker, . A. Schwartz, J. W. Stahl and L. C. Veitch. (2000). Assessment of aviation safety concepts: Phase 1 - Fighter aircraft. Alexandria, VA, Institute for Defence Analysis: 140.

Allen, T. L., G. A. Corliss, A. Schwartz and J. W. Stahl. (2001). Assessment of aviation safety concepts: Phase 2 - Rotary Wing Aircraft (DRAFT). Alexandria, VA, Institute for Defence Analysis: 140.

Applied Psychology Corporation (1961). Field study of threshold ranges for aircraft detection and color identification. Arlington, VA, Applied Psychology Corporation.

Applied Psychology Corporation (1962). Outdoor test range evaluation of aircraft paint patterns. Arlington, VA, Applied Psychology Corporation.

Blackwell, H. R. (1960). Visibility assessment of gray and chromatic paints by a new technique. Washington, D.C., U.S. Coast Guard.

Boff, K. R. and J. E. Lincoln (1988). Engineering Data Compendium, Wright-Patterson AFB.

Chappelow, J. W. and A. J. Belyavin (1992). A Trial to Assess Aids to Conspicuity. Farnborough, Institute of Aviation Medicine: 32.

Chappelow, J. W., A. J. Belyavin, et al. (1993). Aircraft conspicuity and paint schemes: a further trial. Farnborough, Institute of Aviation Medicine.

Charpentier, L. C. S. (2002). Briefing Note on Combat Support (CS) SQNS Requirement for High Visibility Paint Scheme: 4.

Chisum, G. T. (1977). Prediction of Airborne Target Detection. Warminister, PA&, Crew Systems Department, Naval Air Development Center.

Connors, M. M. (1975a). Conspicuity of target lights: the influence of flash rate and brightness. Moffett Field, CA, Ames Research Center.

Connors, M. M. (1975b). Conspicuity of target lights: the influence of color. Moffett Field, CA, Ames Research Center.

Costanza, E. B., S. R. Stacey and H. L. Snyder. (1980). Air-To-Air Target Acquisition: Factors and Means of Improvement. Blacksburg, VA&, Department of Industrial Engineering and Operations Research, Virginia Polytechnic Institute & State Univ.

Crook, M. N., J. A. Hanson and A. Weisz. (1954). Legibility of type as determined by the combined effect of typographical variables and reflectance of background, WADC Tech Report.

Crumley, L. M. and W. Atkinson (1954). Human engineering investigation of the exterior lighting of naval aircraft. Part 1 - a study of the effect of flash rate and on/off ratio on the detectability of flashing lights. Philadelphia, PA, Aeronautical Medical Equipment Laboratory, Naval Air Material Center.

Doyal, J. A., D. P. Ramer, et al. (1994). Visual Contrast Detection Thresholds for Aircraft Contrails. Dayton, Armstrong Laboratory, Crew Systems Directorate, Wright-Patterson AFB**:** 53.

Edwards, G. D. and J. L. Harris (1972). Visual aspects of air collision avoidance: Computer studies on pilot warning indicator specifications. San Diego, CA&, Visibility Laboratory, Scripps Institution of Oceanography.

Ends, E. J. (1967). Why mid-air collisions? New York, NY, Flight Safety Foundation Inc.

Gartner, B. L. and A. J. Pudsey (1965). Anti-collision and navigation lighting systems evaluation, Royal Canadian Airforce Central Experimental and Proving Establishment.

Gerathewohl, S. J. (1954). Conspicuity of flashing light signals: effects of variation among frequency, duration, and contrast of the signals. Randolph Field, TX, USAF School of Aviation Medicine.

Head, T. (2000). Preliminary Report: Glider Conspicuity Trials, RAF Bicester. Cranfield, Cranfield University**:** 4.

Hodgson, W. H. (1959). High visibility painting design for aircraft. San Diego, CA, U.S. Navy Electronics Laboratory.

Hoffmann, H.-E. (1974). A review of the most important established facts about the visibility (Maximum detection range) of aircraft. Deutsche Luftund Raumfahrt,.

Hoffmann, H.-E. and R. H. Buell (1977). Results of field experiments concerning visibility of objects. Oberpfaffenhofen, West Germany, DFVLR.

Howell, W. C. and C. L. Kraft (1959). Size, blur and contrasts as variables affecting the legibility of alphanumeric symbols on radar type displays, WADC.

Hunter, C. A. D. (2002). Briefing Note for the CDS: Colour of Combat Support Squadron CH-146 Helicopters**:** 4.

Katchmar, L. T. and N. H. Azrin (1956). Effectiveness of warning lights as a function of flash rate. Aberdeen Proving Ground, Md., US Army Human Engineering Laboratory.

Kruk, R. and D. Regan (1996). "Collision Avoidance: a Helicopter Simulator Study." Aviation, Space and Environmental Medicine **67**: 111-114.

Laxar, K. and S. L. Benoit (1993). Conspicuity of aids to navigation: Temporal patterns for flashing lights. Groton CT, Naval Submarine Medical Research Laboratory.

Laxar, K. and S. M. Luria (1993). "Flashing Stimuli and Viewing Discomfort." Unpublished manuscript.

Mandler, M. B. (1989). Conspicuity of aids to navigation: extended light sources. Groton, CT., US Coast Guard Research and Development Centre.

Markowitz, J. (1971). “Optimal flash rate and duty cycle for flashing visual indicators.” Human Factors **13**: 427-433.

Meinzinger, M. A. (1999). CH-146 Paint Scheme**:** 4.

Milligan, M. and J. Tennant (1997). Personal Watercraft Conspicuity. Boating Safety Circular. **79:** 5-6.

Portfors-Yeomans, C. and D. Regan (1995). “Direction Discrimination and Speed Discrimination of Motion in Depth Using Binocular Cues Only.” Investigative Ophthalmology and Visual Science **36**(4): S465.

Regan, D. (1993). “Binocular Correlates of the Direction of Motion in Depth.” Vision Research **33**: 2359-2360.

Regan, D. and X. H. Hong (1994). “Recognition and Detection of Texture-Defined Letters.” Vision Research **34**: 2403-2407.

Regan, D. and A. Vincent (1995). “Visual Processing of Looming and Time to Contact Throughout the Visual Field.” Vision Research **35**: 1845-1857.

Regan, D. (1997). Perceptual Motor Skills and Human Motion Analysis. Handbook of Human Factors and Ergonomics. G. Salvendy. New York, Wiley.

Schieber, F. (2002). Searching for Fluorescent Coloured Highway Signs: Bottom-Up versus Top-Down Mechanisms. 16th Biennial Symposium on Visibility, Iowa City, IA.

Siegel, A. I. and K. Crain (1960). Aircraft detectability and visibility: 1. Visual fields for fluorescent and ordinary paints. Wayne, PA, Applied Psychological Services.

Smith, S. L. and N. C. Goodwin (1971). “Blink coding for information display.” Human Factors **13**: 283-290.

Snyder, H. L. and M. E. Maddox (1978). Information transfer from computer generated dot matrix displays.

Thackray, R. I. and R. M. Touchstone (1991). “Effects of monitoring under high and low taskload on detection of flashing and coloured radar targets.” Ergonomics **34**: 1065-1081.

Vincent, A. and D. Regan (1997). “Judging the Time to Collision with a Simulated Textured Object: Effect of Mismatching Rates of Expansion of Size and of Texture Elements.” Perception and Psychophysics.

Wagner, H. G. and I. C. Blasdell (1948). Visibility studies of exterior colour schemes for aircraft at present aluminium coloured, Naval Air Material Centre, Aero. Med. Equip. Lab. Rept.

Wagner, S. L. and K. V. Laxar (1996). Conspicuity of Aids to Navigation: II Spatial Configurations for Flashing Lights, Naval Submarine Medical Research Laboratory.

Wickens, C. D. and Long, J. (1995).Object versus spaced-based models of visual attention: Implications for the use of head-up displays. Journal of Experimental Psychology: Applied, 1, 179-183

THIS PAGE LEFT BLANK INTENTIONALLY

.

DOCUMENT CONTROL DATA SHEET

1a. PERFORMING AGENCY Humansystems, Incorporated, 111 Farquhar St., 2nd floor, Guelph, ON N1H 3N4	2. SECURITY CLASSIFICATION UNCLASSIFIED - Unlimited distribution -
1b. PUBLISHING AGENCY DRDC Toronto	

3. TITLE

U) Conspicuity of the CH-146 Griffon Combat Support Helicopter / Perceptibilité de l'Hélicoptère d'Appui au Combat Griffon CH-146

4. AUTHORS

Tabbeus M. Lamoureux & Paul Stager, Ph.D.

5. DATE OF PUBLICATION August 26, 2003	6. NO. OF PAGES 44

7. DESCRIPTIVE NOTES

8. SPONSORSHIP/MONITORING/CONTRACTING/ASKING AGENCY

Sponsoring Agency:

Monitoring Agency:

Contracting Agency: DRDC Toronto

Tasking Agency: 1 Canadian Air Division HQ, A3 Combat Support

9. ORIGINATOR'S DOCUMENT NO. Contract Report CR 2003-125	10. CONTRACT, GRANT AND/OR PROJECT NO. PWGSC Contract No. W7711-017747/001/TOR, Call-Up Nos. 7747-11 & 7747-17	11. OTHER DOCUMENT NOS.

12. DOCUMENT RELEASABILITY

Unlimited announcement

13. DOCUMENT ANNOUNCEMENT

Unlimited announcement

14. ABSTRACT

(U) The CH-146 Griffon Combat Support Helicopter operates on Air Weapons Ranges in close proximity to fast-moving fighter aircraft. The Canadian Armed Forces has undertaken to improve the conspicuity of the Griffon by considering alternative lighting and paint schemes. DRDC Toronto was requested to assist in this endeavour and to contract a review of the relevant conspicuity literature. This report documents the review and provides a summarising checklist of factors that should be considered when attempting to enhance conspicuity. A number of conclusions are drawn and some recommendations are made. These recommendations refer to positioning and flash-rate of lights, painting the aircraft light colours on the top and dark colours on the underside, painting discontinuous stripes on the main rotor blades, and the continuing use of procedural range control.

(U) L'hélicoptère d'appui au combat Griffon CH-146 s'utilise dans les polygones de tir aérien situés à proximité de chasseurs en déplacement rapide. Les Forces armées canadiennes ont entrepris d'améliorer la perceptibilité du Griffon en examinant diverses configurations en matière de feux et de motifs peints. On a demandé à RDDC Toronto de contribuer à cette recherche et d'octroyer un contrat d'examen de la documentation pertinente sur la perceptibilité. Ce rapport contient des détails sur l'examen effectué et renferme une liste de contrôle résumant les facteurs à considérer pour tenter d'améliorer la perceptibilité. Un certain nombre de conclusions sont tirées, et quelques recommandations sont proposées. Ces recommandations ont trait à la position et à la fréquence de clignotement des feux, à l'utilisation de peintures de couleur claire sur les surfaces dorsales et de couleur foncée sur les surfaces ventrales, à la formation de bandes peintes discontinues sur les pales du rotor principal et à l'utilisation continue du contrôle aux procédures de la distance.

15. KEYWORDS, DESCRIPTORS OR IDENTIFIERS

(U) Aircraft; Conspicuity; Collision avoidance; Detection; Visibility; Warning system; Strobe light; Helicopter; Aircraft paint schemes; Aircraft lighting systems; Flash rate; Duty cycle; Anticollision system; Visual contrast; Luminance contrast