Vision Standards for Aircrew: Visual Acuity for Pilots

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On behalf of
DEPARTMENT OF NATIONAL DEFENCE
as represented by
Defence Research and Development Canada
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Toronto, Ontario, Canada

DRDC - Toronto Scientific Authority
Sharon McFadden

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Abstract

This report documents a study investigating the Canadian Forces (CF) aircrew entrance vision standard. A literature review was conducted to identify a method for establishing bona fide occupational requirements and validated standards for aircrew related visual functions. A protocol for establishing and validating an occupationally based visual acuity standard for the CF pilot occupation was selected. Tasks that have critical visual acuity functions were identified based on data obtained through questionnaires and a focus group session. The study proposes potential task simulations that accurately reflect critical aircrew tasks and an experimental plan to establish vision standards.

Résumé

Ce rapport présente une étude portant sur la norme visuelle fixée pour le personnel navigant au niveau d’entrée en fonction des Forces canadiennes. Une revue de la littérature visant à trouver une méthode pour établir des exigences professionnelles justifiées et des normes validées pour les fonctions visuelles du personnel navigant a été menée. Un protocole d’établissement et de validation d’une norme d’acuité visuelle pour la profession de pilote des FC a été choisi. Les tâches comportant des fonctions essentielles liées à l’acuité visuelle ont été définies à partir de données tirées de questionnaires et d’une séance de discussion en groupe. L’étude propose des simulations de tâches qui reflètent avec exactitude les tâches essentielles du personnel navigant et un plan expérimental de fixation des normes visuelles.

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Executive Summary

The Canadian Forces (CF) requires justification for the current visual acuity recruitment standard for the CF aircrew community. Information was derived from a systematic review of literature focused on the visual functions important in flight operations, a task questionnaire sent to pilots, and a pilot Subject Matter Expert (SME) discussion. A review of available literature revealed no studies or other evaluations that supported or explained the origin of any of the present CF vision standards. No literature was available to substantiate the borrowing of vision standards from other occupations. For these reasons, it is recommended that vision standard development for CF pilots must take into account their own specialized tasks and the environments in which they work. An experimental plan is proposed for assessing the near and far visual acuity requirements of pilots.

The proposed experimental plans involve the conduct of two simulations designed to obtain objective evidence of the relationship between visual acuity level and pilot task performance. The experiments will simulate two piloting tasks identified as representing the highest level of visual acuity demand for pilots. These piloting tasks were identified as requiring excellent visual acuity across all aircraft types. One simulation tests near acuity, with participants reading approach plates during an approach/landing at night. The second simulation tests far visual acuity, with participants locating and identifying air and ground traffic/obstacles during an approach/landing task. Experiments will use positive sphere lenses to examine the effect of parametrically degraded acuity on task performance. It is proposed that the participants will be tested at Best, 6/9, 6/12 and 6/18 in the near acuity simulation and Best, 6/9, 6/12, 6/18 and 6/24 in the far acuity simulation. The results of these simulations will be used to determine the minimum visual acuity requirement for CF pilots.

It is proposed that both experiments should be conducted in a flight simulator. This will allow standardization of lighting levels, environmental conditions and control of size and distance of test items. Investigation into realistic environmental conditions will be conducted to determine if experimentation can be conducted in field conditions. However, consideration must be given to the tradeoff between conducting task simulations in realistic environments and having complete control over the experimental environment.

Consideration is given to the appropriateness of using only visual acuity as the sole measure to test vision. Other components of visual function, their associated diagnostic tests, and levels appropriate to flight operations were investigated. Visual functions included contrast sensitivity, visual fields, glare sensitivity, colour vision, night vision, depth perception, and motion perception. While there are many potential measures of visual function, there is no evidence at this time to suggest that any visual function is more valid than visual acuity for assessing pilot task performance.

Consideration is also given to optical correction. CF policy is to recruit candidates based upon an *uncorrected* visual acuity standard, yet many intermediate and senior level pilots currently rely upon vision correction. Refractive errors necessitating the use of corrective lenses are increasingly prevalent with increasing age. The likelihood of age-related changes in refractive error, an older recruiting age, and the probable requirement for

visual correction with age, highlight a need to consider the recognition of a *corrected* visual acuity standard. Several studies have shown that corrective lenses can be used safely and effectively in aviation. However, there is some evidence that corrected lenses contribute to a higher incidence of accidents, reduce identification capability in combat maneuvers, and contribute to aviation mishaps.

Aspects of refractive error and photorefractive surgery were investigated because consideration of candidates with corrective eye surgery into the CF pilot occupation would have a bearing on the visual acuity standard. Currently, personnel with corrective eye surgery are not eligible for entry into the CF pilot occupation. Concerns include the structural stability of the eye as well as the effects on visual functioning post-surgery.

In order to perform the simulation experiments proposed in this report, a number of action items are recommended. These include (but are not limited to) the following items: determine a suitable simulation test bed or field trial for performing the experiments; measurement of stimulus dimension and environmental variables likely to be encountered operationally; determine the feasibility and timeframe associated with developing the simulator software and hardware changes that will be required in order to conduct the experiments; verify the tasks and associated visual metrics with SMEs; develop an experimental protocol for evaluating the simulation tests and obtain Human Ethics Committee approval; determine a suitable population for participating in the experiments based upon age, experience, gender, aircraft type flown, etc; and conduct, administer and validate a visual function test for a sample of aircrew in order to ascertain their suitability for participating in the experiments. Addressing and resolving these items will be the focus of the next phase of the project.

Sommaire

Les Forces canadiennes (FC) ont besoin d'une justification à l'appui de la norme d'acuité visuelle actuellement en vigueur pour le recrutement du personnel navigant des FC. L'information provient d'une revue systématique de la littérature traitant des fonctions visuelles importantes dans les opérations aériennes, d'un questionnaire sur les tâches envoyé aux pilotes et d'une discussion avec les experts en la matière. L'examen de la littérature a révélé qu'aucune étude ou évaluation ne soutenait ni n'expliquait l'origine des normes visuelles en vigueur actuellement dans les FC. Aucun ouvrage ne justifiait l'emprunt de normes visuelles à d'autres professions. Il est donc recommandé que l'élaboration d'une norme visuelle pour les pilotes des FC tienne compte des tâches spécialisées et de l'environnement de travail qui leur sont propres. Un plan expérimental est proposé pour évaluer les exigences liées à l'acuité visuelle de près et de loin des pilotes.

Les plans expérimentaux proposés prévoient deux simulations visant à recueillir des preuves objectives de la relation entre le niveau d'acuité visuelle et l'exécution des tâches de pilotage. Ces plans simuleront deux tâches de pilotage représentant celles qui exigent le niveau maximal d'acuité visuelle chez les pilotes. Il a été établi que ces tâches exigent une excellente acuité visuelle pour tous les types d'aéronef. La première simulation, qui consiste à demander aux participants de lire les instructions au cours d'une approche/un atterrissage de nuit, évalue l'acuité visuelle de près. La deuxième, au cours de laquelle les participants repèrent la circulation/les obstacles aériens et les obstacles au sol pendant une approche/un atterrissage, évalue l'acuité visuelle de loin. À l'aide de lentilles sphériques positives, on examinera l'effet de la dégradation paramétrique de l'acuité sur l'exécution des tâches. Il est proposé que les participants soient évalués selon la correction optimale, 6/9, 6/12 et 6/18 dans la simulation portant sur l'acuité de près selon la correction optimale, 6/9, 6/12, 6/18 et 6/24 dans la simulation portant sur l'acuité de loin. Les résultats de ces simulations serviront à déterminer l'exigence minimale en matière d'acuité visuelle pour les pilotes des FC.

Il est proposé que les deux expériences se tiennent dans un simulateur de vol afin que les niveaux d'éclairage, les conditions environnementales et le contrôle de la taille et de la distance des items de test puissent être normalisés. Des recherches seront menées dans des conditions environnementales réalistes afin de déterminer si l'expérimentation peut se faire dans des conditions naturelles. Il importe toutefois d'étudier l'arbitrage entre la tenue des simulations de tâche dans des environnements réalistes et le contrôle total sur l'environnement expérimental.

L'étude se penche sur l'opportunité d'évaluer la vision en se fondant uniquement sur l'acuité visuelle. D'autres éléments de la fonction visuelle, les tests diagnostiques associés et les niveaux adaptés aux opérations aériennes ont été étudiés. Les fonctions visuelles comprennent la sensibilité au contraste, les champs visuels, la sensibilité à l'éblouissement, la vision des couleurs, la vision nocturne, la perception de la profondeur et la perception du mouvement. Il y a plusieurs mesures possibles de la fonction visuelle, mais rien ne prouve à l'heure actuelle qu'aucune fonction visuelle ne permet mieux de mesurer la capacité d'exécuter les tâches de pilotage que l'acuité visuelle.

L’étude se penche aussi sur la correction optique. Selon la politique des FC, le recrutement des candidats se fonde sur une norme d’acuité visuelle *non corrigée*, mais bon nombre de pilotes de niveau intermédiaire et supérieur ont actuellement une correction de la vue. La fréquence des vices de réfraction exigeant le port de lentilles correctrices augmente avec l’âge. La nécessité d’envisager l’adoption d’une norme d’acuité visuelle *corrigée* se fait sentir étant donné que des changements dans la fréquence des vices de réfraction et de la correction visuelle en raison de l’âge sont à prévoir et que l’âge du recrutement est repoussé. Plusieurs études ont montré que des lentilles correctrices peuvent être utilisées efficacement et sans danger dans le domaine de l’aviation. Certaines données indiquent toutefois que les lentilles correctrices entraînent un taux plus élevé d’accidents, réduisent la capacité d’identification dans les manœuvres de combat et jouent un rôle dans les catastrophes aériennes.

Certains aspects des vices de réfraction et de la chirurgie photoréfractive ont été étudiés puisque la prise en considération, de candidats ayant subi une chirurgie de correction de la vue pour un poste de pilote dans les FC, aurait une incidence sur la norme d’acuité visuelle. Le personnel qui a subi une chirurgie de correction de la vue ne peut actuellement exercer la profession de pilote dans les FC. Les inquiétudes ont trait à la stabilité structurale de l’œil et aux effets de la chirurgie sur le fonctionnement visuel.

Un certain nombre de mesures sont recommandées pour que l’on puisse mener les expériences de simulation proposées dans ce rapport. Ce sont notamment les suivantes : choisir un banc d’essai ou un essai sur le terrain pour la tenue des expériences; mesurer la dimension des stimuli et les variables environnementales susceptibles d’être présentes dans les opérations; déterminer s’il est possible d’apporter au logiciel et au matériel du simulateur les changements nécessaires à la tenue des expériences et le délai à prévoir pour y arriver; vérifier les tâches et les mesures visuelles connexes avec les experts en la matière; mettre au point un protocole expérimental pour l’évaluation des tests de simulation et obtenir l’approbation du Comité de déontologie humaine; déterminer une population qui pourrait prendre part aux expériences en se fondant notamment sur l’âge, l’expérience, le sexe et le type d’aéronef utilisé; et tenir, administrer et valider un test de fonction visuelle pour un échantillon du personnel navigant afin de vérifier s’il peut prendre part aux expériences. L’étude et le règlement de ces points seront au cœur de la prochaine étape du projet.

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Acknowledgements

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1 Introduction

This report documents a study investigating the Canadian Forces aircrew visual acuity entrance standard. The objectives of this project were to:

1. Review the currently available literature on the establishment of bona fide occupational requirements and validated standards for vision;
2. Identify a suitable protocol for establishing and validating an occupationally based vision standard for aircrew;
3. Select (or design) simulation tests that accurately reflect critical tasks of aircrew; and,
4. Recommend a visual acuity standard and an appropriate test procedure for aircrew selection.

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1.1 Background

Changes in human rights legislation and court challenges have helped to prompt increased efforts to develop and validate selection standards that are occupationally and medically relevant. It is now being recognized that a listing of essential functions without a linkage to occupational requirements is incomplete at best. Vision selection standards are critical to the effective and safe conduct of many tasks and this is particularly evident for many of the tasks involved in flight operations. Good vision is a vital requirement for mission success in many aviation tasks. Although the importance of other sensory systems in completing complex tasks should not be overlooked, vision is the only sensory system that is likely to be used to its fullest capacity during flying tasks (Swamy, Joseph, Aravind & Veval, 2002).

The level of visual functioning necessary to effectively conduct essential job functions is the only appropriate basis for a professionally appropriate vision standard. Efforts to develop relevant vision selection standards were initiated in a study, contracted by the Surgeon General, to investigate the feasibility of developing valid vision standards for all Canadian Forces (CF) occupations. Further study was contracted by the Directorate of Health Services Delivery to develop a suitable test methodology for establishing standards for land, sea, air and support environments (Casson, 1995). Air Command tasked DRDC Toronto to review the CF aircrew vision standards and propose amendments that considered operational conditions currently encountered by aircrew. An aircrew survey was conducted that identified tasks perceived to be visually demanding and gathered informed opinions on potential vision standards (Heikens, Gray, O'Neill & Salisbury, 1999). However, the survey did not validate the suggested vision standards, nor did it link existing and recommended vision standards to task performance. The work conducted in the current study builds upon previous efforts to establish a valid, occupationally and medically relevant standard for CF pilot vision.

To ensure that the entrance standard for pilots is set at a level that is both fair and safe, the CF required a review of the current visual acuity standard for the pilot community. Specifically, the “uncorrected visual acuity standard” (i.e. the medical standard for the ability to see detail without the use of spectacle or contact lens correction) is to be determined. This requires determining the level of visual acuity required to perform pilot tasks safely, efficiently and to an acceptable performance level.

This document outlines the methodology, results and proposed simulations to be administered in order to develop a bona fide visual acuity standard for CF pilots. This included an extensive literature review used to develop a work plan to establish and validate a vision standard for aircrew. Critical vision tasks were identified that can be used in experimentation to propose a vision standard directly associated with task performance. Simulation tests that accurately reflect the critical tasks with high visual acuity demand were developed for testing purposes to ensure that the acuity standard is both occupationally and medically relevant, as well as compliant with human rights legislation.

The importance of a bona fide vision standard will help to ensure that qualified candidates are not excluded. The rejection of qualified persons imposes great costs to the CF considering all of the recruitment, testing, training and selection costs are lost. Further to this, a qualified individual may be rejected for erroneous reasons. Moving down the hiring list for selection also imposes risk due to the selection of a lesser qualified candidate, as the placement on a hiring list is reflective of potential job performance (Carmean, 1998).

The scope of this project work was to support the requirement of DRDC Toronto to develop, validate and implement a task-oriented, performance-based visual acuity standard for Canadian Forces pilot recruitment purposes.

1.1.1 Canadian Human Rights Act

The Canadian Human Rights Act prohibits the denial of employment opportunity (i.e., the training, initiation or continuation of employment) to an individual on the basis of disability unless it can be demonstrated that the applicant cannot meet the Bona Fide Occupational Requirements (BFOR) of the job. According to the Act, whenever an employer devises methods of testing an individual's performance of a job, the procedure must include:

1. Identification of the essential tasks which make up the requirements of the job;
2. Identification of the skills and capabilities required to perform the essential tasks of the job;
3. Methods which evaluate the ability of the individual to carry out the essential tasks of the job by any reasonable method; and
4. Standards which do not exceed the minimum requirements of the job.

Canadian Human Rights Reporter Supplement, 1982 TR/82-3

Any study designed to determine appropriate and defensible vision standards must meet the requirements of this legislation in order to be justifiable and fair and must be supportable with evidence rather than opinion alone.

In addition to demonstrating that certain levels of visual acuity are required for effective and safe performance, it is also necessary to show that there is a real and substantial risk to people and property if this standard is not met.

1.1.2 Determining a Vision Standard

A fair and effective vision standard must be based on the Bona Fide Occupational Requirements (BFOR) for visual acuity. This requires an analysis of the tasks conducted by pilots and an identification of those tasks that:

1. Are essential to program completion;
2. Present a high risk of property damage and/or personal injury if performed incorrectly; and
3. Have a high visual acuity requirement.

These tasks will represent the BFOR for a visual acuity standard. They will also form the basis of an experimental design that will help to determine the visual acuity standard necessary to perform these tasks in an operational environment.

1.2 Current Vision Standard

Currently, the Canadian Forces Pilot recruitment standard is based upon a number of physical tests, including multiple vision tests. These vision tests include the following items:

- Distance visual acuity: 6/6 in better eye and 6/9 in the other eye (both uncorrected)
- Near visual acuity: N5 (reading distance), N14 (100cm) in the better eye and N6 (reading distance), N18 (100cm) in the worse eye
- Refractive error (in diopters): +2.50 Hyperopia, -0.25 Myopia, $\pm$ 0.75 Astigmatism and allowable Cyclopegia
- Heterophoria (in prism diopters): No more than 10 Exophoria, 10 Esophoria and 2 Hyperphoria
- Visual fields: clinical confrontation test and, if indicated, Humphries VF test
- Stereoacuity: Titmus Tester
- Interocular pressure: 22mmHg or less with the Goldman applanation tonometry
- Colour vision: If <17/21 Pseudoisochromatic colour plates (PIP) test + Blue-Yellow plate for tritan defect, then tested with Holmes-Wright lantern, or Farnsworth Lantern assessment. If one or more errors occur on either lantern test, then the applicant is determined to be CV3
- Detection of previous Keratorefractive surgery: use the standard for Corneal topography as indicated in INFO PUB 61/115/22

The current study is focused on the CF pilot visual acuity recruitment standard, although consideration has been provided for other vision parameters and possible simulation of these parameters (see Section 6 Discussion).

1.2.1 Report Outline

This report documents the following items:

- Introduction - provides the background information and report outline;
- Method - outlines the information gathering framework and methodology;
- Results -
  - Visual Functions – defines various visual parameters, associated literature and commentary from focus group discussions.
  - Visual Correction – discussion of optical correction and photorefractive surgery.
  - Tasks – outline of essential tasks that have a critical vision component and recommendations for tasks to simulate.
  - Proposed Test Scenarios – an experimental plan to assess the visual acuity recruitment standard of CF pilots.
- Discussion - the vision-related functions and variables that should be considered; and
- Conclusion and Recommendations – action items required in developing a bona fide vision standard.

2 Methodology

The methodology used to gather information to develop a defensible, task-oriented visual acuity standard for the CF pilot occupation, is outlined below. This methodology is based on previous experience and an extensive review of literature on visual functions in flying. The methodology includes a review of literature and legal challenges and the identification of tasks that have critical visual acuity functions, based on data obtained through questionnaires and a focus group session. The results of these tasks were analyzed to propose task scenarios that accurately reflect critical aircrew tasks and an experimental plan to establish vision standards.

2.1 Literature Review

In order to determine if the current visual acuity standard is reasonable, a comprehensive review of scientific literature from both military and civilian sources was completed. A literature review of the existing Canadian Forces visual acuity pilot standards for recruiting was conducted, as well as a review of the visual acuity standards in other countries. A brief search was also performed regarding recent relevant legal challenges and the Canadian Human Rights Act to determine the requirements for a 'Bona Fide Occupational Vision Requirement'. Further, a brief internet search was performed to gather information related to visual acuity and high demand tasks. Scientific and medical literature related to pilot tasks and visual acuity was reviewed and the task analysis also included a review of the Occupational Analysis Unit of the Directorate of Manpower Planning literature. Literature was reviewed on visual functions and task performance in related occupations in order to assess the existing evidence on task based visual acuity requirements. A number of vision standards developed for other occupations (e.g., police, divers) and non-military aircrew also provided guidance to the project objectives. EndNote, an electronic bibliographic database, was used to collect and organize reference materials.

The literature review provided the following list of parameters of visual functions which should be considered by the CF:

1. Monocular and binocular uncorrected visual acuity (UCVA): UCVA refers to visual acuity tested without optical correction. What determines the minimum requirement for acuity without correction (i.e. what determines safe performance in an emergency when spectacles are lost)?
2. Monocular and binocular best corrected visual acuity (BCVA): BCVA refers to acuity tested with the best-possible optical correction in place. What determines the minimum requirement for acuity with correction?
3. Degraded Visual Environments: How are the visual abilities listed above influenced by poor environmental conditions?
4. Pilot Aging: How do age-related changes in vision affect performance on pilot tasks as a function of viewing conditions?

These parameters were considered throughout the task analyses as well as the test scenarios that were developed to study the effect of degraded vision on the performance of CF pilot tasks.

A review of LegalTrac articles was conducted for legal challenges related to vision standards for pilots. No articles were identified that related to the Canadian Forces and vision standards for pilots. One case was identified involving piloting tasks. An Arizona jury awarded substantial damages to a promising young commercial pilot grounded for life after Lasik surgery, due to poor preoperative screening. Although he still has at least 20/20 vision, side effects from the surgery impaired his ability to see clearly at night. He saw glare from landing lights. (Holt, 2002)

Findings of the literature review are integrated into the results below.

2.2 Task Analysis

The emphasis on a task-oriented and performance-based vision standard was a major component of the project objectives. Only by assessing the vision standard against critical user tasks will the CF be able to ensure it is applicable and valid. A bona fide occupational vision standard must be based on demonstrations that the standard is actually required to perform job-related tasks. Using non-task-related vision requirements has ramifications that are more detrimental than an occasional lawsuit, as it can result in the placement of persons in positions in which they cannot perform the essential functions of their job.

The task analysis was conducted in two main thrusts; a preliminary questionnaire analysis and a focus group session with experienced pilots representing all aircraft types.

2.2.1 Pilot Vision Task Questionnaire

The literature was reviewed to identify particular tasks associated with high degrees of risk in terms of pilot safety. A questionnaire was generated based on tasks identified in the Vision Survey of CF Aircrew document (Heikens et al., 1999). This Aircrew Operational Vision Survey was sent to all operating CF pilots. Pilots were asked to answer a number of questions related to the visual demands of the tasks they perform. The results of the survey were analyzed in terms of the type of aircraft flown. Aircraft were divided into the following groups:

- Tactical Helicopter
- Search and Rescue Rotary Wing
- Maritime Patrol Rotary Wing
- Transport
- Maritime Patrol Fixed Wing
- Fighter
- Primary Rotary Wing Trainer
- Primary Fixed Wing Trainer

The results of the survey identified the highest rated visually demanding tasks as indicated by the CF pilots, for each aircraft type.

Using the results of the 1997 Vision Survey of CF Aircrew (Heikens et al., 1999), a questionnaire was developed for the current project to assist in identifying the critical, high risk tasks associated with military piloting occupations. The tasks that received a high rating in terms of visual demand from the survey were selected for the Pilot Vision Study Questionnaire (Appendix A) which was sent to subject matter experts (SMEs) prior to the focus group session. Each pilot was asked to fill in the applicable survey section based upon the type of aircraft they were currently flying. The pilots were asked the following questions in relation to the visually demanding tasks they perform:

- What type of task is this? (Routine/ Non-Routine/ Emergency)
- What is the vision requirement for performing this task? (Near vision/ Intermediate vision/ Far vision/ Variable vision requirements)
- What kind of environmental conditions is the task performed under? (Bright sunshine/ Rain/ Fog/ Snow/ Bright sunshine + Ground snow/ Night/ Dusk or Dawn)
- What is the lowest level of experience required to perform this task? (New recruit (0-2 years of experience)/ Junior pilot (2-5 years of experience)/ Intermediate pilot (5-10 years of experience)/ Senior pilot (10 + years of experience)

The results from this questionnaire allowed the experimenters to focus on specific tasks that were analyzed in greater detail with the pilots in an SME session. Tasks that were selected for additional analysis were mission and safety critical tasks, tasks common across all aircraft, emergency tasks and difficult tasks to perform in terms of visual acuity.

This process identified specific tasks to analyze in more detail with the SMEs in terms of demand for visual acuity, which was subsequently required for the selection of experimental test scenarios.

2.2.2 Subject Matter Expert Focus Group Session

A Subject Matter Expert (SME) focus group session was conducted to further investigate the visual acuity requirements for CF pilots. The objective of the focus group was to assess the current CF pilot visual acuity entrance standard, verify the tasks performed by CF pilots, discuss the visual demands of these tasks and develop an outline for a task-based simulation providing justification and guidance to update the entrance standard.

Twelve SMEs participated in a focus group discussion. All SMEs had flying experience with a variety of aircraft and came from different Canadian Airforce bases (12 Wing Shearwater, Central Flying School Wing, Transport Rescue Standardization/ Evaluation Team Trenton, 1 Wing Headquarters Kingston and MPSET Greenwood). The participants' average total flight time was 6220 hours.

The SME session provided information to determine the essential tasks performed by CF pilots that have a critical vision component. The SME session was designed and conducted to:

- Discuss tasks performed by CF pilots
- Validate the task list across all aircraft
- Determine the tasks common across all aircraft
- Discuss the pilot tasks in terms of mission criticality and safety
- Determine and characterize the visual characteristics of critical pilot tasks
- Review emergency procedures and critical incidents
- Discuss comprehensive and realistic pilot flying scenarios,
- Breakdown the scenarios into component tasks and
- Determine the tasks that may be feasible to simulate

This process was used to ensure that the final standard meets the requirements of the Canadian Human Rights Act.

The SME session was led with a dual perspective approach, focusing first on tasks and secondly on visual functions. The task portion of the SME session was designed to gather information related to vision critical tasks based on previous research, such as the vision survey. The discussion also identified tasks that are common across all aircraft types including training and operational conditions. The second portion of the SME session focused on the visual functions and characterized elements of pilot tasks that made them visually demanding.

2.2.2.1 Critical Incident Documentation (Behavioural Examples)

Critical incidents were discussed during the SME session. This process involved obtaining information about previous incidents related to task performance. The SMEs were asked to recall particular incidents of either outstanding or inferior job performance, or situations where a particular incident occurred or a specific ability was required. For each behavioural example the information obtained included:

1. The circumstances that preceded the incident;
2. What the employee did specifically that was effective or ineffective, or required a specific ability; and
3. The consequences or result of the incident in question.

The SMEs were asked to provide particular behavioural examples where vision was involved in these critical incidents.

A summary of the task analysis results, including the results from the Vision Tasks Questionnaire and SME session is provided in the results section.

2.3 Propose Task Simulations and Experimental Design

Upon completion of the SME Sessions, an experimental plan was developed. Two test scenarios involving simulation experiments were developed to test the effects of varied visual acuity on the task performance of CF pilots. The first experiment is a near visual acuity task that requires participants to extract critical task information from approach plates during an approach/landing at night. The second experiment is a distance visual acuity task that involves locating and identifying ground traffic/obstacles during an approach (landing) or reconnaissance. The goal of both simulations is to provide a controlled experimental environment that simulates the visual acuity aspects of each task and allows for objective measurements of performance. A proposed experimental design is outlined in the Results section of this report.

It should be noted that information related to pilot tasks and procedures in this report has been generated directly from the SME session participants and is therefore, based on personal descriptions of their tasks and procedures. As a result, the tasks and procedures described in this report do not necessarily correspond directly with published regulations or procedures.

3 Results - Visual Functions

The results of the study are presented in this section and the following three sections of the report. The visual functions in aviation, including optical correction and photorefractive surgery are discussed in Section 3, SME questionnaire results in Section 4, the tasks selected for simulation in Section 5 and the proposed experimental plan to simulate these tasks in Section 6.

Although there is no doubt that military flying is visually demanding (e.g., Sekuler, Kline & Dismukes, 1982), existing knowledge does not allow precise specification of the visual functions that are critical to aircrew performance (e.g., Casson, 1995). Two reasons account for this: first, relatively few experimental studies directly relate to this issue, and secondly, the data that are available are generally not sufficient to allow quantitative characterization of specific visual functions for complex dynamic tasks such as flying an aircraft. Thus, the literature review that follows will explore the relationship between different aspects of vision and aircrew tasks as well as those in related task domains.

3.1 Far Acuity

3.1.1 Description

Resolution acuity refers to the smallest detail (gap or feature) that can be resolved, usually in a centrally fixated (i.e., foveal) stationary target presented at a defined distance. It can be measured with corrective lenses (corrected acuity) or without (uncorrected acuity). When measured with the observer's best optical correction for the test distance, it is referred to as "best visual acuity" (BVA). Measurement is usually done separately for each eye (monocular acuity) but can also be measured for both eyes together (binocular acuity). Due to probability summation, binocular acuity is typically 15 to 20% better than monocular acuity.

Acuity is typically measured using size-graded rows of high-contrast "optotypes" (see Figure 3.1). The observer's task is to either identify the target on each row (e.g., Snellen or Sloane letters), or to indicate the orientation of a repeated target form (e.g., bars or gratings, "lazy Es", or Landolt Cs). Acuity measures are thus indicative of an observer's ability to resolve fine spatial details, such as the text on a distant object (e.g., sign, ship name, aircraft number) or small alphanumeric characters or symbols on instrument panel displays and controls.

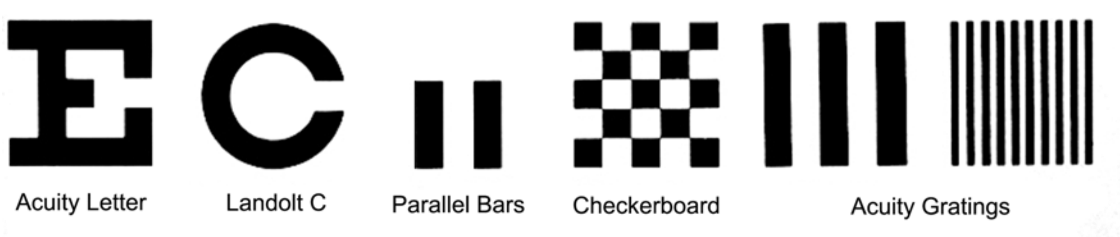

Figure 3.1. Examples of high-contrast acuity targets (Optotypes).

Far acuity is usually measured at optical infinity for the eye (i.e., at 20 ft or 6 m) and is usually denoted using one of two equivalent notations. When expressed using the common "Snellen fraction" (e.g., 20/40), the "numerator" refers to the test distance in feet and the "denominator" to the distance in feet at which an observer with "good" acuity could resolve a critical target detail of the same size. The metric version of the Snellen fraction expresses the corresponding information in meters (e.g., 6/12).

Acuity can also be expressed more directly in terms of the minimum visual angle subtended by the smallest resolvable critical feature (e.g., the gap in a Landolt C), usually in minutes of arc (minarc or arcmin). An acuity level of 1.0 minarc is equivalent to Snellen 20/20 (6/6 metric), and 2.0 minarc to 20/40 Snellen (6/12 metric). Measured under ideal viewing conditions, the best human acuity is about 20/10 (6/3 metric) or 0.5 minarc.

Acuity is a common and highly useful measure of spatial visual function for several reasons. It can be easily measured by personnel with limited training using a wide selection of readily available tests and it is quite reliable despite potentially significant deviations from standard clinical conditions (e.g., Hawkins, 1995). It also provides an excellent basis for clinical refraction (i.e., optical lens prescription) and is sensitive to several optical (e.g., cataracts) and sensorineural disorders (e.g., macular degeneration). Acuity is, however, affected by a wide range of stimulus and observer variables. It is degraded by dim lighting, low target contrast, target crowding, target motion relative to the observer and oblique target orientation. It is also subject to the effects of observer age, pupil size, monocular versus binocular viewing and quality of optical correction (i.e., blur).

Good acuity, along with colour vision, is mediated by the *cone photoreceptors* of the retina that are functional at relatively high (i.e., photopic) levels of illumination. Consequently, low stimulus luminance impairs both of these visual functions. For a young observer with good visual health, acuity can improve with target luminance up to about 350 cd/m^2, a level equivalent to good interior lighting. Due to the progressive decline with age in retinal illuminance associated with a decline in resting pupil size (*senile miosis*) and increased opacity of the lens of the eye, the luminance range over which the acuity of older observers can benefit is considerably extended. Conversely, poor viewing conditions tend to exacerbate the acuity problems of older observers as well as those of any age with refractive problems such as myopia, hyperopia and astigmatism.

Optical blur, low luminance and low target/background contrast are known to degrade acuity. However, their interactive effects in affecting performance on different visual tasks are not as well understood. Johnson and Casson (1995) evaluated the potential interactions of these three variables by comparing the Landolt C acuity of trained psychophysical observers (each with 20/20 acuity or better) over five levels of contrast (6 to 97%), four levels of luminance (.075 cd/m^2 to 75 cd/m^2) and nine levels of positive sphere blur (0 to 8 D). They found that the effects of the blur, low luminance and reduced contrast eroded acuity in an additive rather than interactive fashion. This led them to conclude that their data could allow for the prediction of acuity–mediated performance in realistic viewing conditions. For example, they predicted that an individual with 20/20 acuity at high luminance would decline to 20/60 in low luminance and under conditions of both low luminance and low contrast, to 20/100.

3.1.2 Literature Review

The current standard, outlined by the Air Standardization Coordination Committee (ASCC, 2003) for the uncorrected distance acuity of Canadian Forces pilots is 6/6 in the better eye and 6/9 in the other eye. This is somewhat higher than that of most other ASCC nations. For example, the corresponding standard for uncorrected acuity in Australia is 6/12 in each eye (each eye correctable to 6/6), in New Zealand, 6/9 in each eye (each correctable to 6/6) and in the United States, 6/21 in each eye (each correctable to 6/6). Among ASCC countries, only the U.K. has a more demanding uncorrected acuity standard than Canada (6/6 uncorrected each eye).

Meeting an initial entry acuity standard does not mean that an observer's acuity will not later decline to a level below the established standard due to visual disease and/or normal aging. There is a well-documented decline in acuity with age. A small loss in uncorrected acuity may be evident in individuals in their 30s or earlier, even among relatively select observers (e.g., Gittings & Fozard, 1986). The decline in best corrected acuity among healthy, well-corrected observers is likely to be noticeable much later, not until approximately 50 to 60 years of age (e.g., Elliott, Yang, & Whitaker, 1995). In less select "epidemiological" populations, age-related acuity declines tend to be more significant (e.g., Attebo, Mitchell, & Smith, 1996; Klein, Klein, Lee, Cruickshanks & Chappell, 2001).

It is also clear that military personnel selected for good acuity are not immune to age-related visual deterioration. In response to lowering the uncorrected acuity standard for Japan Air Self Defense Force personnel, Kikukawa, Yagura and Akamatsu (1999) studied the distance acuity of 752 non-aviation personnel from age 20 to 45, 94% of whom met the entry standard for student pilots. The proportion of the sample needing corrective lenses increased with age from 15.8% to 37.1%. Over the 25 year time-frame of the study, pilots with the best initial acuity showed a smaller decline in acuity and also less need for corrective lenses than those with worse initial acuity. The authors noted that lowering the initial standard was associated with an elevated risk of visual acuity loss as the pilots aged. Presumably, careful and systematic visual and medical screening could ameliorate this risk. That, at least, is the implication of a study by Miura, Shoji, Fukumoto, Yasue, Tsukui and Hosoya (2002). They found that increasing the allowable age from 60 to 63 years for Japanese airline transport pilots did not appear to be associated with any decline in safety, a result that they attributed to the medical screening regimen. Similarly, while Eyraud and Borowsky (1985) found that the profile of accident types changed with age for fighter, attack and helicopter pilots, the overall accident rate for pilots 37 to 47 years of age did not differ significantly from that of pilots aged 22 to 37.

Changes in acuity after entry into the military, whether due to aging or some other cause(s), highlight the need for ongoing screening if visual readiness is to be maintained. A study of the prevalence of substandard acuity of 207 members of several different communities in the U.S. Air Force (Erneston, Ricks, Tate, & Ana, 1996) found that 54% had not had a professional eye exam in the previous two years, 24% were not mobility ready, 3% had inadequate acuity relative to the standard and 1.9% had ocular disease.

A larger scale study (Buckingham, Cornforth, Whitwell & Lee, 2003) found problems of visual readiness to be even more prevalent in the different branches of the U.S military (USA, USAF, USMC, USN). Of the 4825 active duty personnel tested, 83.3% were not vision ready, 10.4% had substandard acuity and 73.8% had eye-health related deficiencies. There was, however, considerable variability in these data across the different service branches. The prevalence of personnel who were deemed not visual acuity ready ranged from a low of 3.5% in the USAF to a high of 15.4% in the USN.

Far acuity is a measure of an observer's ability to resolve fine detail at distance and it is predictive of performance on a wide range of everyday visual tasks, such as Horton, performed by aircrew. For example, acuity is related to face recognition (e.g., Bullimore, Bailey, & Wacker, 1991), identifying suspicious behaviour or determining if a person is carrying a weapon (e.g., Good & Ausberger, 1987; Johnson, Casson & Zadnik, 1992) and reading distant text materials such as license plates (e.g., Kiel, Butler, & Alwitry, 2003; Sheedy, 1980) or road signs (e.g., Horton & Joseph, 2002).

Acuity has also been related to performance on a range of tasks in the marine environment including the identification of marker buoys (Donderi, Kawaja, Smiley, Henderson, & Zadra, 1994), the detection and identification of navigation lights, the detection of a simulated man-over-board and the detection of ship-to-ship signals (Casson, Gibbs & Cameron, 1999b). In the latter task, performance fell to near-chance levels when acuity was degraded to 20/40 (6/12). Even a small reduction in acuity has been shown to impair the detection of a life raft in daylight search and rescue (e.g., Donderi, 1994).

3.1.3 Related Tasks

The SME discussion identified a number of common pilot tasks that are challenging to the visual system in terms of far visual acuity. Target identification tasks (for example reading ship lettering from a far distance in order to identify the ship type and allegiance, or identifying other aircraft as friendly or enemy) were reported to be challenging far acuity tasks. This is due to the inherent risk associated with closing proximity to an enemy ship, aircraft or other armed vehicle. The further away a pilot determines key aspects of a target, such as determining friendly or enemy status, direction of heading or orientation, the safer a pilot will remain. SMEs also reported the need to be able to see runway hazards and distant air traffic. For example, one SME recalled an incident in which he saw a small private plane crossing into his flight path that he was able to avoid, due to dependable far acuity.

3.2 Near Acuity

3.2.1 Description

Like its far counterpart, near acuity refers to the ability to resolve fine details usually in high-contrast stimuli. Near acuity is basically a measure of the visual resolution needed for reading and similar close tasks and is conventionally measured and corrected (as needed) at normal reading distance (16 in. or 40 cm). Although near acuity is often specified using the familiar "20/N" Snellen notation, technically, like far acuity, it should be specified in terms of the distance at which it is measured (e.g., as 16/32 not 20/40, or in metric terms as 40/80 rather than 6/12). This issue highlights the advantage of specifying both far and near acuity in terms of minarc, where 1.0 minarc specifies the same angular resolution for both far Snellen (20/20 or 6/6) and near Snellen (16/16 or 40/40).

'N-notation' is another system that is used to specify near acuity, especially for reading text. N charts are composed of continuous "paragraphs" printed in a Times New Roman font that ranges from smallest size (N5 - corresponding roughly to a resolution of 1.6 minarc or a Snellen near acuity of 16/26) to the largest (N60 - about 19.2 minarc or 16/307). There is a direct mathematical relationship between N size and font size (e.g., the N12 font is half the size of N24 and twice the size of N6). It should be noted, that to read at an optimal rate, print should be about twice the observer's acuity threshold (Whittaker & Lovie-Kitchen, 1993).

Near acuity is also affected by many of the same variables as far acuity (i.e., lighting, target contrast, crowding, motion, orientation, observer age, pupil size, monocular versus binocular viewing, and optical correction). Uncorrected near acuity, however, is particularly vulnerable to the effects of ocular aging. Near stimuli demand more refractive (accommodative) power from the lens of the eye; a function that declines more or less linearly with age from its peak at about 10 years of age. By age 60, due to sclerosis in the lens and possibly changes in the ciliary muscle, virtually all accommodative amplitude is lost in both the general (c.f., Kline & Scialfa, 1996) and medically-screened pilot populations (e.g., Szafran, 1969).

The associated recession of the near point of vision, known as *presbyopia*, is often noticeable by approximately 40 years of age, at which time the observer is likely to need an optical "add" to provide the increase in optical power (e.g., bifocal, trifocal or progressive lenses) to focus near stimuli. As the aging eye progresses toward a "fixed-focus" state, the observer's optical correction will increasingly determine the ability to focus on items at different distances. Trifocals have a near (40 cm), far (6 m) and intermediate distance correction (depending on the prescription, usually between 50 and 100 cm). The refractive power of progressive lenses increases toward the lower near segment and they provide a relatively continuous distance correction, although they demand good alignment of the gaze through the spectacle relative to display distance. With a well-prescribed bifocal, the wearer is corrected for near and far but not intermediate viewing distances such as those characteristic of instrument panels. Depending on the accommodative ability that remains, the instrument panel may be out of focus (i.e., blurred), or cause eyestrain if extended accommodative exertion (i.e., more than half the observer's remaining accommodative reserve) is needed to achieve focus.

The problems of blur and eye-strain for observers with low accommodative capacity are depicted graphically in Figure 3.2 as a function of age and display distance. It shows how a good optical correction becomes increasingly essential for an older pilot, even one with excellent far acuity. This issue has received longstanding attention in the aviation/vision research literature (e.g., Backman, & Dow-Smith, 1975; Markovits, Reddix, O'Connell, & Collyer, 1995).

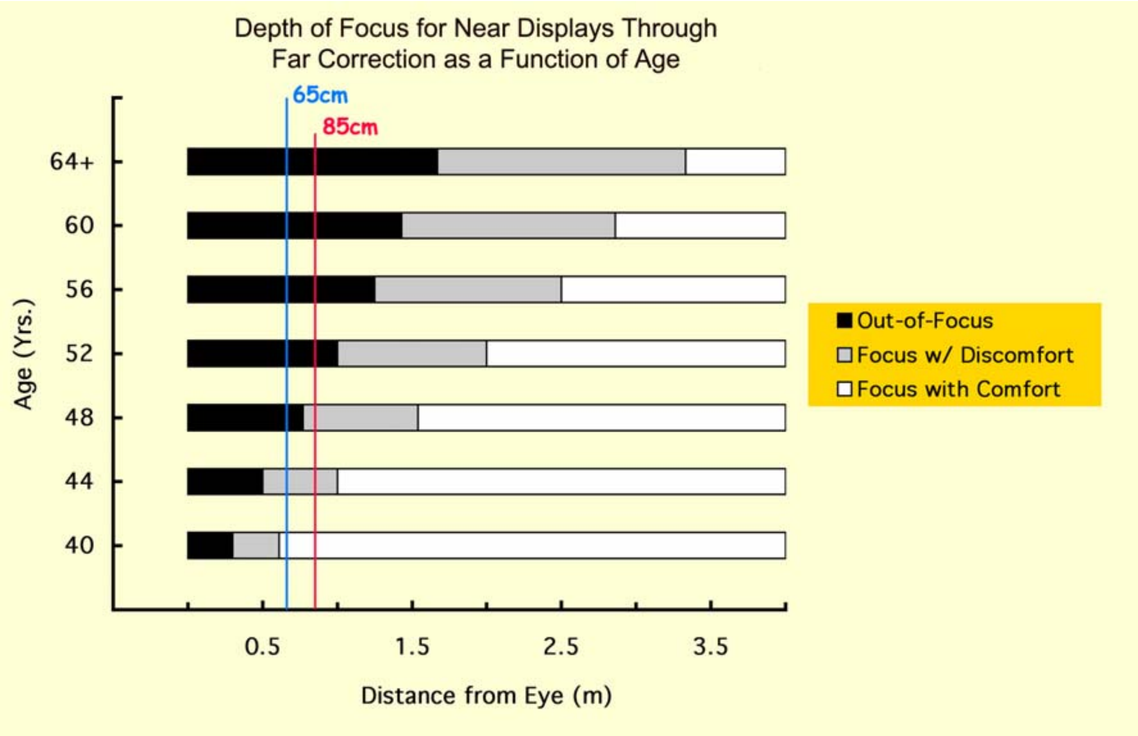

Figure 3.2. The effects of age-related accommodative loss on focus and eye-strain with extended viewing for observers with low-accommodation. Source: Kline, Caird, Ho, & Dewar (2002).

3.2.2 Literature Review

The near acuity standard for CF aircrew (ASCC, 2003) is specified in N-notation form for both reading distance and 100 cm. For the better eye, the standard is N5 at reading distance and N14 at 100 cm; for the worse eye, N6 is specified at reading distance and N18 at 100 cm. Presumably, the 100-cm distance is specified to indicate the need for good acuity at intermediate cockpit instrument display distances.

Effective near and intermediate-distance acuity is essential for a wide range of operational tasks in aviation and related environments, including reading navigational charts and control system labels, and monitoring flight systems. Reduced acuity impairs the ability of Coast Guard employees to carry out near clerical tasks similar to those for sea-going personnel (Donderi, Kawaja, Smiley, Henderson, & Zadra, 1994) and also degrades the ability of avionics technicians to read printed wire codes in the electrical compartment of large aircraft (Casson, Gibbs, & Cameron, 1999a).

Optically degraded near acuity has also been shown to affect pilot cockpit performance. Mann and Hovis (1996) examined the ability of 15 instrument-rated pilots to carry out simulator instrument-flight-rules (IFR) approaches under four levels of optically degraded acuity. Although most of the pilots were able to maintain decision height under all blur levels due to the vernier acuity-like nature of the task display, localizer positions were degraded during the inbound phase in daytime lighting. The major effect of degraded acuity was to impair the pilots' ability to read approach plates and to set proper radio frequencies. Under daylight conditions, approximately 30% of the participants could not read the approach plates with a near acuity of .50 logMAR (about 3 minarc or 16/50). This finding is similar to that of Draeger, Brandl, Wirt, and Burchard (1989) who found that acuity below 6/7 hindered pilots' ability to read charts and maps accurately at the time of approach. The importance of near acuity for this task is significant, considering the numerous small details that must be resolved on approach plates (see Figure 3.3).

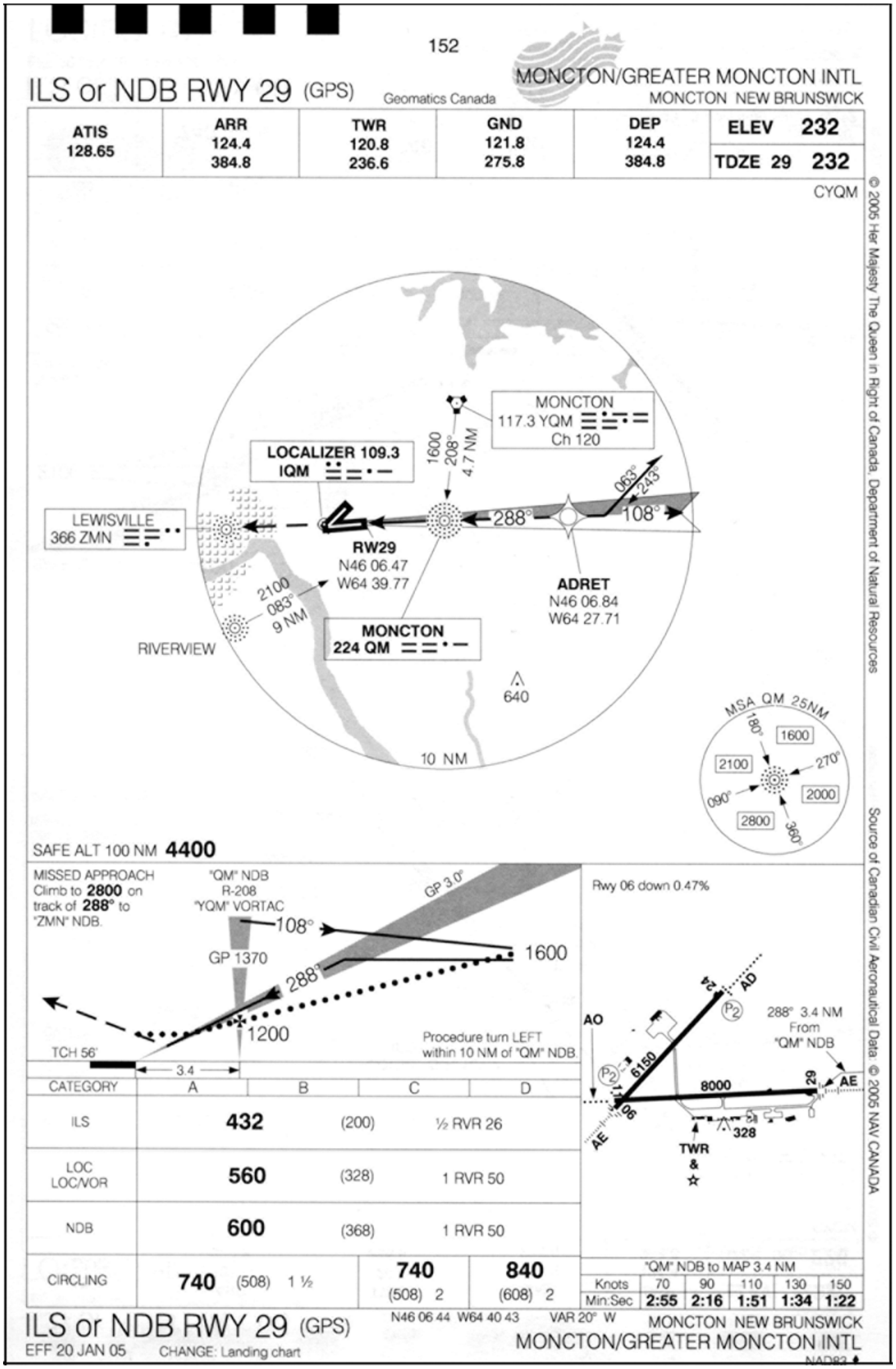

Figure 3.3. Approach plate for Greater Moncton International Airport – Atlantic Region. Source: Geomatics Canada, Dept of Natural Resources, 2005.

3.2.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual system in terms of near visual acuity. One task that is common across all aircraft is reading approach plates in the cockpit. The SMEs indicated that approach plates have become increasingly challenging to read and decipher due to the constant updating of flight information, which in turn, clutter the plates. This task can be made further challenging when combined with a vibrating cockpit, or while wearing Night Vision Goggles (NVGs). Other challenging near visual acuity tasks performed by pilots include reading Visual Flight Rules (VFR) maps and contour maps, viewing CRT instrumentation and the weather radar display and interaction with the flight management system. Depending on the aircraft, this may have to be done under green light, blue-filtered light or red light. One SME recalled a situation in which an older pilot had difficulty reading an approach plate and noted that in such situations the co-pilot (in multi-crew aircraft) will often take responsibility for checklist and reading tasks.

3.3 Contrast Sensitivity (CS)

3.3.1 Description

Stimuli in the natural environment are not generally high in luminance contrast relative to their background. In recognition of this, basic and clinical research increasingly examines the possibility that low-contrast measures may be more sensitive than high-contrast tests for identifying many eye health problems and/or predicting task performance in viewing conditions affected by stimulus contrast. In general, studies support this view, showing that some observers who are able to identify crisp black and white targets on a regular acuity chart may have inordinate difficulty in seeing at night, in a dimly lit room, or in glare. It has been documented that CS measures are better than visual acuity in predicting success when detecting and identifying common objects (Owsley & Sloane, 1987), in discriminating highway signs (Evans & Ginsburg, 1985) and for understanding the everyday visual problems of aging drivers (Schieber, Kline, Kline, & Fozard, 1992).

Several different CS test systems have been developed to determine observer sensitivity (1/contrast threshold) to low contrast stimuli. Some of these tests are analogous to acuity charts in using letters, but they differ in that contrast sensitivity rather than minimum stimulus size is measured. For example, the Pelli-Robson contrast sensitivity chart (Pelli, Robson & Wilkins, 1988) shown in Figure 3.4, uses fairly large letters of a constant size that decrease in contrast for each group of three letters from the top to bottom of the chart. Normally presented at three meters, this test primarily measures the ability to discern contrast in large (i.e., low spatial frequency) stimuli. As implied by its name, the Small Letter Contrast Test (SLCT) uses small letters (equivalent to 20/25) across 14 lines of decreasing contrast to test CS at four meters (e.g., Rabin, 1996). The Regan low-contrast letter test (Regan & Neima, 1983) is composed of a series of charts each with letters of different size but of systematically varied contrast. As a result, it assesses contrast sensitivity over a broader domain of spatial size than the Pelli-Robson or SLCT charts.

Figure 3.4. A sample Pelli-Robson contrast sensitivity chart. Pelli, D. G., Robson, J. G., & Wilkins, A. J., 1988. Copyright © 2002 D.G. Pelli and J.G. Robson. Distributed by Haag-Streit.

Letter charts for testing CS have the virtues of familiarity for both the administrator and patient, often require little special equipment and are also quickly and easily scored. They are, however, generally less precise and less comprehensive than tests based on sinusoidal luminance gratings (e.g., Fig. 3.5). By assessing an observer's ability to discriminate luminance contrast differences in sinusoidal gratings of varied spatial frequency (i.e., grating fineness), the contrast sensitivity function (CSF) provides a comprehensive measure of spatial vision ability. Numerous computer-based grating-based CS testing systems of this type exist, but most are custom to different labs and are not standardized in testing method, spatial frequency, or testing conditions.

A few systems, such as the Functional Acuity Contrast Test (FACT – www.contrastsensitivity.net) device and its predecessor, the chart-based (near and far) Vistech Contrast Testing System (VCTS - Vistech Consultants, 1988), however, have been developed for more general use. On Vistech charts (see Figure 3.5), spatial frequency increases from the top to bottom row and contrast decreases from left to the right. Sensitivity for each spatial frequency is based on the rightmost (i.e., lowest-contrast) grating for which orientation is correctly reported.

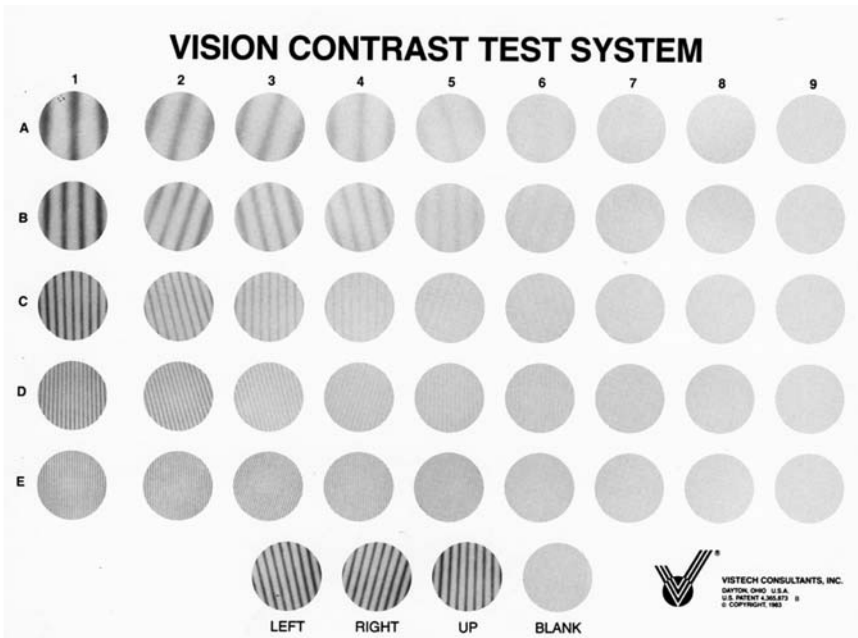

Figure 3.5. Sample VCTS 6500 contrast sensitivity chart. Source: Vistech Consultants (1988).

In most studies, age effects on the CSF are generally negligible at low spatial frequencies, but an emerging age deficit is seen for gratings of intermediate and higher spatial frequency (e.g., Elliott, Whitaker, & MacVeigh, 1990; Kline, Schieber, Abusamra & Coyne, 1983; Owsley Sekuler, & Siemsen, 1983). The extent of prior CS loss also appears to be a robust predictor of later acuity loss in older observers (Schneck, Haegerstrom-Portnoy, Lotta, Brabyn, & Gildengorin, 2004).

3.3.2 Literature Review

Sensitivity to contrast appears to be particularly useful for predicting performance in the presence of optical aberrations, glare and dim light. For example, scores on the SLCT appear to be more sensitive than acuity, to both subtle optical defocus (Rabin, 1994) and reduced target luminance (Rabin, 1995). CS and low-contrast acuity are highly sensitive to glare effects with cataracts (Elliott, & Bullimore, 1993) and CS is more sensitive than high-contrast acuity to optical degradation associated with photorefractive surgery (e.g., Verdon, Maloney, & Bullimore, 1995). Sensitivity to low contrast also appears to enhance effective performance on a wide range of real-world tasks, including many in aviation. This includes sensitivity to the optical effects of aircraft windscreens on visibility, especially in glare (Hughes & Vingrys, 1991). It has been shown to be more strongly correlated than acuity with performance on a simulated search and rescue task (Stager & Hameluck, 1986). CS also appears to be superior to conventional acuity measures for predicting a pilot's ability to detect small air-to-ground targets in an aircraft simulator (Ginsburg, Evans, Sekuler & Harp, 1982) as well as target detection in the field (Ginsburg & Easterly, 1983).

Numerous studies have found CS measures to be related to performance on a diverse range of aircrew tasks (e.g., Rabin, 1995) and significant levels of research have been devoted to the development of CS measures for aircrew screening (e.g., Gray & McFadden, 1987; McFadden & Kaufmann, 1993; Grimson, Schallhorn & Kaupp, 2002; Swamy, Joseph, Aravind & Vevai, 2002). No standard has yet been set for CS in military aviation, however, nor will one be feasible without further validation research. Different CS tests produce highly variant results (e.g., Elliott & Whitaker, 1992; Hitchcock, Dick & Krieg, 2004; McFadden, 1994), they often lack acceptable test-retest reliability (Pesudovs, Hazel, Doran, Elliott, 2004) and general population norms are not suitable for application to the visually-select aircrew community (Swamy, Joseph, Aravind, & Vevai, 2002). The effort to establish a CS standard may be encouraged especially when considering the results of a study conducted to establish large-group normative data for screening student naval pilots using the SLCT (Grimson, Schallhorn, & Kaupp, 2002). The naval student pilots (N = 107) scored significantly better than a military control population that included both aviation (N=366) and non-aviation personnel (N=185), leading the authors to conclude that the SLCT showed potential for use as a screening test during the induction exam of military pilots.

3.3.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual acuity system in terms of contrast sensitivity. Target identification in conditions of low contrast (for example identifying a grey ship silhouette against sea water in order to identify the ship type and allegiance) was reported to be a challenging low contrast acuity task. Similarly, when flying an aircraft into a forested area, the pilot must determine the tallest tree and its relation to the aircraft, as this will affect the chosen flight path and altitude. However, determining the tallest tree is difficult when there is very little contrast differentiating trees from one another. This task is made even more difficult when performed under sunset or dusk conditions, as the haze associated with such times lowers all contrast detail.

Another common pilot task that challenges the visual system in terms of contrast sensitivity is identifying targets in the Search and Rescue (SAR) environment. For example, finding a white aircraft in the snow, or a green tank in a forest are both difficult tasks due to the lack of contrast between the targets and their respective backgrounds. One SME recalled a time when he was tasked to go to a crash site and was provided with its exact position, but he could not find the site as it blended in so well with the surrounding forest environment. He eventually found the site when sunlight, reflected from part of the vehicle for which he was searching for, attracted his attention.

3.4 Visual Fields and Useful Field of View

3.4.1 Visual Fields

3.4.1.1 Description

The visual field is a measurement of the spatial extent of vision. Depending on the facilities available to a lab or clinic, the field is usually measured in one of three ways. The confrontational exam is a quick evaluation of the visual field performed by an examiner sitting directly in front of an observer. With one eye covered, the observer may be asked to look at the examiner's eye and indicate the locations at which they can see the examiner's hand. On the tangent-screen exam, the observer fixates a central target and informs the examiner when he/she can see an object entering the peripheral vision along various orientations. In automated perimetry, the observer is seated in front of a concave dome and fixates on a central target. A computer-driven program flashes small lights at different locations within the dome and the observer presses a switch to indicate the lights that are seen. These responses are compared to age-matched norms to determine the presence of defects within the visual field. For a visually healthy human observer, the horizontal visual field for one eye may extend 100^0 to110^0 temporally and 60^0 nasally. Due to binocular overlap, this produces a full horizontal field extent of about 180^0. Vertically, the inferior field may extend to 70 to 75^0 and the superior field to about 60^0. Overall field size may contract due to an eye disease (e.g., glaucoma, retinitis pigmentosa). There can also be “holes” in the visual field due to eye injury (e.g., solar damage, detached retina) or disease (e.g., macular degeneration, diabetic retinopathy).

3.4.1.2 Literature Review

Peripheral vision plays a critical role in visually guided behavior (e.g, walking, driving, low-level flying, etc.) and in directing attention in surveillance and search tasks. For this reason, all ASCC nations specify a visual field standard for military flying (ASCC, 2003). For CF aircrew, the visual field can be established initially by the confrontational method and if the need is indicated, by follow-up automated perimetry using the Humphries VF device. Loss of peripheral vision (not defined) or the presence of scotoma are both cause for candidate rejection.

Visual changes or conditions that limit the information available from the peripheral visual field have been shown to degrade performance on a range of tasks involving mobility and field search. A large-scale study that evaluated the visual fields of 10,000 drivers (Johnson & Keltner, 1983), found that binocular field losses were associated with accident and violation rates more than double those of age- and sex-matched control participants. The accident and violation rates of drivers with field losses in only one eye, however, were not elevated.

Some simulator studies have shown that field losses due to eye disease produce a decrement in driving performance (e.g., Hedin & Lovsund, 1987; Szlyk, Brigell & Seiple, 1993). However, more recent studies (e.g., Myers, Ball, Kalina, Roth & Goode, 2000) indicate that current perimetry tests are not strong predictors of an individual's driving performance relative to the useful field of view test (see section 3.4.2 following).

Due to the 3-D open field nature of the aviation environment, intact visual fields may be even more critical for some flying tasks than for driving. For example, in daytime low-level flight, visual flow provides critical information about speed and altitude (Foyle, Kaiser, & Johnson, 1992). The field of vision also appears to affect estimates of closing speed to collision with (for example) another helicopter in a simulator setting (Kruk, & Regan, 1996). Given the importance of peripheral vision in the cockpit, it has been suggested that the field losses due to glaucoma represent a potential problem for pilots due to the relatively long interval between exams (Schwartz, Stern, Klemm, Draeger, & Winter, 1996). It may also be important to distinguish the effects of field losses initially from those observed after an adaptation period. For example, there is evidence that the effects of visual field reduction due to monocular loss can be compensated for on some tasks, if the pilot has sufficient opportunity to adapt to the loss (Kochhar & Fraser, 1978).

3.4.1.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual system in terms of visual fields. The pilots indicated that some of the cockpit warning lights are located primarily in the peripheral field of vision (FOV), rather than the direct field of view. Depending upon the aircraft, a warning light may be blinking, flashing, and/or may have an auditory component (not all alarms in the peripheral field of view have an auditory component). Therefore, peripheral vision is extremely important in detecting and identifying cockpit warning lights. Further, the pilots reported that NVGs have a 40-degree FOV that severely limits their viewing capability of cockpit warning lights.

Pilots also reported that they use their peripheral FOV to detect birds, other aircraft and to determine depth perception. Similarly, the peripheral FOV is important for stability while flying. It is used by pilots to ascertain where they are in comparison to the horizon and indicates whether the aircraft is level in comparison to the horizon (determining attitude: pitch, roll and yaw). This task is more difficult to perform at night without the visual cues provided by the horizon.

Related to this, landing on a ship at night is a difficult task, considering there are few peripheral FOV cues available. In this instance, a pilot may rely on the co-pilot to provide information related to depth and proximity to the ship. Personnel on the ship may also drop flares, with the intent of aiding pilot vision (although this can actually hinder pilot vision with the complete loss of their night vision adaptation- See Section 3.7 Night Vision).

One situation the helicopter pilots must try to avoid by using their peripheral vision is the prevention of a 'Snowball' effect when landing the helicopter. The pilots must try to prevent stirring up elements with the helicopter (such as snow, sand, dust, etc) or they may lose their references to external cues such as altitude and aircraft angle in relation to the ground. The peripheral FOV is necessary for detecting a snowball forming adjacent to the aircraft door, which acts as a cue to the pilot to increase speed before visibility is lost.

3.4.2 Useful Field of View

3.4.2.1 Description

The Useful Field of View (UFOV) refers to the ability to locate, identify and discriminate visual stimuli presented so briefly as to preclude eye movements. A higher order task than simple field size, it measures selective and divided attention as well as rapid visual processing. In its usual form, the UFOV measure asks observers to identify a central stimulus while also locating a peripherally located target in the presence of distracter elements. The size of the UFOV varies with display characteristics and task demands. It is reduced when attentional demands are increased by the addition of a secondary discrimination task in central vision (Ball, Beard, Roenker, Miller & Griggs, 1988) or when the number of background distracter stimuli is increased (Scialfa, Kline & Lyman, 1987).

Performance on UFOV tasks declines with age (e.g., Ball, Roenker, & Bruni, 1990), a change that appears to reflect a reduction in the efficiency with which information can be extracted from complex scenes. This loss is exacerbated when attention must be divided between a central and peripheral task (e.g., Sekuler, Bennett, & Mamelak, 2000). Among older drivers, the UFOV appears to account for nearly 20% of crash variance in both retrospective and prospective studies (see Ball, Owsley, Sloane, Roenker & Bruni, 1993). Also, studies in simulated traffic environments have shown that prolonged driving can cause a contraction in the UFOV (Rogé, Pebayle, Hannachi, & Muzet, 2003). A similar contraction in the spatial extent of visual attention has been attributed to the “cognitive-capture” effects of head-up displays in aircraft (Prinzel, 2004).

3.4.2.2 Literature Review

Although the research literature on the predictive utility of UFOV for driving safety and performance is growing rapidly, there seems to be very little comparable work in the field of civil or military aviation (searches for “UFOV and pilots”, “UFOV and flying, “UFOV and aviation” and similar terms returned no citations). As a result, the potential of the UFOV test for screening aircrew remains largely unexplored. Considering that peripheral visual feedback seems to be highly effective for supporting attention in event-driven data-rich environments such as modern aircraft (Nikolic & Sarter, 2001), the utility of higher-order peripheral vision assessment techniques in aviation is likely to increase in the future.

3.4.2.3 Related Tasks

In the fixed wing environment, the UFOV is important when taxiing the aircraft. In order to maintain the aircraft on the runway, the UFOV is used to avoid for example, hangers and other airplanes. A wide UFOV is also important in identifying the presence of birds as well as the location of other aircraft in the landing order. Further, it is essential in preventing movement illusions that may occur when performing single light approaches to a ship or runway at night, or when performing hovering activities.

3.5 Glare Sensitivity & Recovery

3.5.1 Disability Glare

3.5.1.1 Description

When light from a strong “veiling” source falls onto the retina, it reduces image contrast. The nearer the glare source is to the line of sight, the greater the problem. The effects of such *disability glare* are usually measured in terms of the impact on acuity or contrast sensitivity. Although disability glare can occur during daytime (e.g., flying into the sun early or late in the day, sunlight reflected from snow-covered terrain) it is even more prevalent in low-luminance conditions (e.g., bright lights at night). The problems associated with disability glare generally increase with age, primarily because the senescent lens of an older viewer scatters light to a greater degree than its younger counterpart (e.g., Brabyn, Haegerstroem-Portnoy, Schneck, & Lott, 2000; Guirao, Gonzalez, Redondo, Geraghty, Norrby & Artal, 1999).

Anderson and Holliday (1995) measured the effects of car headlight glare (off, low beam and high beam) on motion direction discrimination with blurred vision and simulated intraocular lens opacities. Simulated opacities that had little or no effect on daytime static acuity, significantly reduced contrast sensitivity for moving targets and led the authors to suggest that driver visual screening should include testing under nighttime driving conditions. The effects of disability glare are likely to be even more critical in military aviation.

3.5.1.2 Literature Review

A variety of lighting sources, including sunlight, fire, flares, explosions, even on-board camera flash systems (e.g., McFadden, 1982), can produce disability glare in aviation. There is also evidence that glare from the sun has contributed to accidents in civil aviation, most frequently during day time clear-weather approaches and take-offs (Nakagawara, Wood, & Montgomery, 2004). Glare has been shown to reduce nighttime on-road driving performance and pedestrian detection, especially that of older drivers (Theeuwes, Alferdinck & Perel, 2002). Relatively little research, however, has been devoted to studying the effects of glare on various aircrew tasks and no standard disability-glare resistance standard has been set for pilot entry into the air service in any of the ASCC countries. This is not surprising given the considerable inter-individual variability in susceptibility to disability glare, even among pilot groups (Temme, Still, &

Fatcheric, 1995) and that there are dozens of different systems but few standard methodologies for testing it.

Elliott and Bullimore (1993) compared the reliability, discriminative ability and validity of five different glare testing systems (the Miller-Nadler, Vistech MCT8000, Berkeley, van den Berg Straylightmeter, and Brightness Acuity Tester (BAT) used with Pelli-Robson and Regan charts). They found that contrast sensitivity and low-contrast acuity from the Pelli-Robson, Regan and Bekeley tests provided similar reliable, discriminative and valid measures of cataract and concluded that without decent chart design and psychophysical methods, the design and geometry of the glare source are of little importance. However, when Tan, Spalton and Arden (1998) compared the Straylightmeter and BAT before and after removal of posterior cataracts, they found that the glare testing in combination with acuity provided more information than contrast sensitivity and that glare effects were better assessed by the Straylightmeter in comparison to the BAT.

3.5.1.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual system in terms of glare sensitivity and recovery, specifically, disability glare. All of the SMEs reported that they experience disability glare when taking off and landing on a runway directly facing the sun (sunset or sunrise). Bright sunshine also inhibits the ability to read aircraft instrumentation and disability glare is a problem for pilots flying over water in the sunshine. It can also make formation flying and judging the direction of other aircraft travel very difficult. Some aircraft have flip-down glare shields that the pilots may use to alleviate glare sources (although these only work well if the aircraft is flown in one direction, as they typically make the view too dark in the direction opposite to the sun).

One SME reported disability glare associated with landing on a hospital pad at night. Very strong lights were shining on the landing pad. These lights were blindingly bright in comparison to the dark surroundings, which in turn inhibited the pilot’s dark adaptation and peripheral vision.

3.5.2 Discomfort Glare

3.5.2.1 Description

Discomfort glare refers to light effects that are annoying but do not necessarily interfere with task performance. A wide variety of sources can produce discomfort glare, including lighting fixtures, headlights, strong luminance differences between adjacent surfaces as well as reflections from snow, windows, CRT screens, windshields and aircraft canopies. Discomfort increases directly with the intensity of the source and inversely with the angle between the glare source(s) and the line of sight. Discomfort glare also tends to be greater for flashing or scintillating light sources than for stable sources (King, 1972). Primarily a psychological phenomenon (Saur, 1969), discomfort glare is measured by subjective rating.

3.5.2.2 Literature Review

Sensitivity to discomfort glare appears to increase with observer age in the general population (e.g., Hughes & Neer, 1981). This may also be applicable to military pilots, but little research has been devoted to the topic.

3.5.2.3 Related Tasks

SMEs reported some discomfort glare is experienced when approaching bright runway lights from a dark environment. It was also reported for the flashbulb effect from mortar flashes and for ground illumination in the vicinity of an aerodrome.

3.5.3 Glare Recovery

3.5.3.1 Description

Due to the protracted recovery of retinal sensitivity after exposure to a strong transient glare source (e.g., oncoming vehicle headlights at night), visibility can be adversely affected well after the initial exposure. Bichao, Yager and Meng (1995) have shown that exposure to transient glare raised discrimination thresholds by .5 to .75 log units more than a steady source, an effect that was even more pronounced and enduring in the visual periphery. Further to this, older observers take longer to recover from exposure to a strong transient glare source (e.g., Carter, 1994; Elliott & Whitaker, 1990). This is particularly true if the targeted viewing object is low in contrast relative to its background. When Schieber (1994) measured the ability to identify low-contrast letter pairs after exposure to glare, he found that older observers required three-times longer to recover than did their younger counterparts.

3.5.3.2 Literature Review

One study found protracted glare recovery time to be associated with an increased risk of automobile accidents (Roy & Choudhary, 1985), while the results of another study indicate that glare recovery can be predicted by low contrast acuity (Schneck, et al., 2004). There is little research in the public domain on the effects of glare recovery time on performance of aviation tasks (as assessed by online searches for glare recovery and scotomatic glare). As for disability and discomfort glare, no standard method has been accepted for measuring glare recovery.

3.5.3.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual system in terms of recovery from glare specifically, transient sources. Flying directly into bright sunshine and then changing direction to have the sun located directly behind the aircraft, was a problem noted by all SMEs. Of specific concern was the long recovery time required after exposure to glare. SMEs indicated that glare shields and sunglasses help to alleviate this problem. Similarly, when taking off from a runway at night, pilots may be surrounded by bright lights and then quite suddenly enveloped in complete darkness. This inhibits dark adaptation to the outside environment as well as the ability to read and interact with important elements within the cockpit (for example, approach plates, aircraft instrumentation, etc.). Glare is also a problem when using paraflares to aid in landing or when flying in the ‘flashbulb’ effect from mortar fire. When attempting to land in the cover of darkness, if a paraflare is used it provides immediate bright light and then complete darkness again (similar to mortar fire), inhibiting the visual system. Finally, the SMEs reported that glare was a concern when flying in and out of cloud cover when it is inter-mixed with bright sunshine.

3.6 Colour Vision

3.6.1 Description

An observer’s ability to process colour information determines the contribution that colour contrast can make to form perception. Normal trichromatic colour vision allows an observer to discriminate colour differences in the full spectral range. However, colour discrimination can be difficult or even impossible for those with colour vision deficiencies unless the information is conveyed redundantly (e.g., by shape, size, temporal property, or brightness). Colour deficiencies are generally distinguished depending on whether they are *congenital* (present at, or soon after birth), or *acquired* (develop as a consequence of environmental exposure, disease or trauma).

There are three types of congenital colour vision deficiency, *monochromacy*, *dichromacy* and *anomalous trichromacy*. Monochromats, due to the absence of cone photoreceptors, are truly “colour blind” and also have very poor acuity. Dichromats, having only two types of cone photopigment, need only two wavelengths to match any wavelength so they experience colour over a smaller range than do trichromats. The three forms of dichromacy, *protanopia*, *deuteranopia*, and *tritanopia*, are labeled as to the types of cone photopigment that is missing. Protanopia and deuteranopia, both sex-linked deficiencies, are far more common among males than females. Both involve problems discriminating red and green - short wavelengths are seen as blue and long wavelengths as yellow. Tritanopia, which is quite rare, leads to a confusion of blues and yellows - greens and reds are seen at short and long wavelengths, respectively. Like normal trichromats, anomalous trichromats need three wavelengths to match any other wavelength, but they use them in different proportions than those with normal colour vision. They may also have more difficulty discriminating some wavelengths than those with normal trichromatic colour perception, due to a convergent shift of the red and green pigment spectra.

Colour vision deficiencies may also be acquired as the consequence of disease, trauma or toxicity. Such deficiencies tend to be equally prevalent in males and females, asymmetric between the two eyes and less stable over time than congenital deficiencies. Acquired deficiencies are more likely to manifest as yellow-blue rather than red-green defects. A wide range of causal factors can be involved including normal aging, diabetic retinopathy, cataract, age-related maculopathy (ARM), and medications. Although it is not a profound effect, colour discrimination tends to decline with age, more so for short than long wavelengths (Kinnear & Sahraie, 2002).

3.6.2 Literature Review

Consistent with the need for effective colour perception in aviation, the CF pilot entry standard (ASCC, 2003) specifies a two-stage contingent testing protocol. Initial screening is carried out using a pseudoisochromatic plate (PIP) test (e.g., the Ishihara) and includes a Blue-Yellow plate (for tritan defect). If the score on the PIP is less than 17 out of 21, a Holmes-Wright or Farnsworth lantern test (FALANT) is administered. Any errors on the lantern test leads to a designation of CV3, the minimum colour standard that will allow dichromats and severe anomalous trichromats to enter the CF.

For the normal trichromatic observer, colour can be a powerful aid to a visual search and identification task (e.g., Christ, 1975; D'Zmura, 1991). Bowman and Cole (1981) found that observers with good colour vision and acuity were able to use colour-coded navigation lights to facilitate determination of intruder aircraft orientation and direction. Redundant colour coding has been shown to facilitate overall search speed on airborne CRT displays (Luder & Barber, 1984) and to enhance speed and reduce errors on cockpit identification/search tasks (Macdonald & Cole, 1988).

In contrast, deficient colour vision can impede performance on a diverse range of tasks (e.g., Cole, 1993; Cole, 2004). Steward and Cole (1989) found that almost 90% of dichromats and about two-thirds of anomalous trichromats reported difficulties with everyday tasks that involve colour. Approximately half of the dichromats and approximately 20% of the anomalous trichromats experience difficulty distinguishing traffic lights and carrying out their jobs. O'Brien, Cole, Maddocks and Forbes (2002) reported that deuteranopia reduced the attention conspicuity of traffic signs and signals. Defective colour vision has also been shown to impede the acquisition of information from redundantly coded video displays (Cole & Macdonald, 1988) and polychromatic sonar screens (Scholz, Andresen, Hofmann, & Duncker, 1995).

Ishihara and Farnsworth Munsell colour vision tests have been shown to predict performance on buoy identification at high illumination levels and engineering performance (e.g., color naming, direction and colour of piping arrows) under low illumination (Donderi, et al., 1994). Mertens and Milburn (1998) evaluated the predictive validity of 13 colour vision tests by comparing the performance of colour-normal and colour-deficient observers on three air traffic control tasks (flight progress strips, aircraft lights and colour weather radar). They concluded that a high level of colour vision ability was essential to accurate task performance; however, they also noted that three of the tests evaluated had overly high false-alarm rates.

The available research presents a compelling case in favour of the need for colour vision standards for occupational tasks where human observer colour judgment cannot be supplanted by automation (Vingrys & Cole, 1986; Vingrys & Cole, 1988; Cole, 2004). To be occupationally relevant, however, tests must be matched to the colour demands encountered in operational conditions. In that regard, it should be noted that the Ishihara PIP test, which can be administered in the first stage of colour testing for CF pilot entry, may fail some observers who are colour-normal (Hovis & Oliphant, 2000). Conversely, the Farnsworth lantern test, which can be administered in stage two, will fail observers with severe red-green colour vision deficiencies, but it does not allow a determination of the type or severity of the colour deficiency (Birch & Dain, 1999).

3.6.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual system in terms of colour vision. The VFR maps, approach plates, contour maps, CRT instrumentation, weather radar, ground proximity warning system, flight management system, runway approach lighting and runway lights all have associated colour coding. For example, the VFR maps use colour to distinguish relief and contours.

The SMEs reported that the aircraft instrument panels are colour coded (for example, weather radar) and yet there is no secondary or redundant coding associated with the colour. This is important when considering that small changes in coloured lighting can severely affect people with poor colour vision. For example, the Tactical Helicopter pilots at times are required to fly with laser eye protection (a light green filter) that affects all viewable colours and even completely washes out some colours.

The ability to distinguish colour is also important for target detection and identification. The SMEs reported that SAR pilots must be able to identify (for example), an orange life raft in the ocean, or white smoke on an ocean with whitecaps. Also, the ability to determine green from red is extremely important, especially to determine the meaning of a flare (normally colour coded), or to distinguish the direction of travel of other aircraft by viewing their red or green navigation lights.

3.7 Night Vision

3.7.1 Description

As ambient illumination levels decline from day to night-time levels, the visual system undergoes a corresponding increase in sensitivity. This process, called *dark adaptation*, is mediated by two complementary retinal photoreceptor systems; together they provide the human observer with visual sensitivity over a wide range of light intensities (about 12-log units). The cone-based *photopic* system, which operates at higher light (luminance levels in the range of 10^0 to 10^7 cd/m^2), provides the observer with fine spatial resolution (i.e., acuity) and color vision. This system reaches its maximum sensitivity within the first 8 to 10 minutes of dark adaptation. The highly sensitive but colour-blind rod-based *scotopic* system mediates perception at low light levels from about 10^{-6} to 10^1 cd/m^2. It may not reach its maximum sensitivity for 30 to 40 minutes into the dark adaptation process.

The transition from the photopic to scotopic system accounts for the loss of acuity and colour vision that occurs with falling light levels. The relatively narrow 1-log unit luminance range over which both systems are functional (from 10^0 to 10^1 cd/m^2) is called *mesopic* vision. Essentially then, there are two levels of night vision (e.g., Hovis, 2000). In one (mesopic), there is sufficient light for the cones to provide some colour vision and enhance acuity (e.g., distant objects illuminated at night by automobile headlights). In the other (scotopic), the conditions are so dark (e.g., a dark overcast night) that only rods operate, acuity is very poor and no colour is seen. For some observers, very low-light levels can also trigger a process known as a *dark shift*, in which the eye's accommodation level increases. The resultant shift of focus to within a meter or two of the observer causes distant objects to be blurred in a phenomenon known as *night myopia*.

With age, there a progressive loss of both the photopic and scotopic sensitivity (e.g., Kline & Scialfa, 1996); however, the scotopic decline is considerably more pronounced (Jackson & Owsley, 2000). As a result, driving and everyday visual tasks become steadily more difficult for older observers to carry out in dim light (e.g., Kline, Kline, Fozard, Kosnik, Schieber, & Sekuler, 1992).

3.7.2 Literature Review

Although dark adaptation is critical for tasks that must be carried out in low light, its measurement is difficult, time-consuming and requires specialized facilities and highly-trained personnel (e.g., Casson, 1995; National Research Council, 1985). These factors may account for the absence of a night vision standard for pilot entry for most ASCC countries, including Canada (ASCC, 2003). That does not mean, however, that nighttime tests could not make an important contribution to pilot vision screening.

When Fowlkes, Kennedy, Hettinger and Harm (1993) studied the relationship between the dark focus of accommodation and simulator sickness among young observers, they found that those who became ill were more likely to demonstrate a tendency toward night myopia. The authors hypothesized that the relationship might be mediated by common parasympathetic activity. Noting that night vision goggles, virtual environments and head-up displays all produce similar visual symptoms, they suggested that changes in dark focus should be measured in these settings as well.

Not surprisingly, some night vision tests appear to be much more effective than conventional daytime measures for predicting pilot performance in mesopic and scotopic conditions. A study that compared the utility of more than 20 night vision tests (Glovinsky, Belkin & Hammer, 1992), found three that were predictive of an observer's ability to detect military targets at night: dark adaptation rate (DAR), scotopic retinal threshold (SRT) and mesopic contrast sensitivity (CS). Follow-up research to evaluate the reliability of these tests for young observers over a two- and six-week period (Levy & Glovinsky, 1997) found acceptable measurement stability for SRT and CS, but not the DAR measure. The investigators concluded that the assessment of the night vision of pilots and military personnel could be based on scotopic sensitivity after 30 minutes of dark adaptation and contrast sensitivity (1.5, 3.0, 6.0, and 12.0 c/deg) under mesopic illumination.

By significantly enhancing nighttime acuity and contrast sensitivity (e.g., Rabin, 1993), night vision goggles (NVGs) allow pilots to operate far more effectively in low-light conditions. NVGs, however, are not without problems. Numerous human factors concerns are associated with their use (Manton, 2000). For example, light adaptation to intensified images can handicap pilots who set cockpit luminance too low (Howard, Riegler, & Martin, 2001). The latter investigators found that a luminance difference of 2.0 or more log units increased response time to cockpit instrumentation by up to 5.5 seconds among pilots in their 20's and by 8 to 15 seconds for older pilots.

In multi-crew cockpits, problems of luminance adaptation are occasionally mitigated with the flying pilot using NVGs and the co-pilot monitoring the flight information displays (Task & Griffin, 1982). NVGs may also present difficulties to pilots using optical correction. Spectacle wearers tend to have worse acuity than non-spectacle wearers through NVGs (Silberman, Apsey, Ivan, & Jackson, 1994) and pilots who need bifocals may need to use a larger near-add segment to achieve decent close vision (Farr, 1989). Finally, many older pilots may need an optical correction that exceeds the corrective limits of the NVG (Stone, Sanders, Glick, Wiley & Kimball, 1980).

Problems of distance (depth) judgment (e.g., Sheehy & Wilkinson, 1989) and spatial disorientation with NVGs can be acute, especially in rotary wing aircraft operations (Holmes, Bunting, Brown, Hiatt, Braithwaite & Harrigan, 2003). An analysis of U.S. Army helicopter accidents found that approximately 45% of spatial-disorientation accidents were associated with the use of NVGs. Accident rates with them were more than five times higher than daytime rates (Braithwaite, Douglass, Durnford, & Lucas, 1998). Research has shown that problems of spatial disorientation with NVGs can be reduced with effective training that emphasizes adjusting the NVG to the least-minus (myopia) correction required (Kotulak & Morse, 1994) and using a standard target and adjustment procedure (DeVilbiss, Ercoline, & Antonio, 1994).

3.7.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual system in terms of night vision. Landing approaches at night are demanding, especially in the rain. The SMEs also indicated that twilight and late dusk lower the contrast between objects, whether flying over water or land. One example they provided was the ability to detect a smaller hill directly in front of a larger hill when flying towards the hills. In terms of night vision, there may not be enough distinguishing factors between the larger and smaller hill to determine that there are actually two distinct hills in the flight path. This is especially dangerous for a low-flying fixed wing plane (in comparison to a helicopter), as the pilots of these aircraft have less time to react and fewer options for action. The SMEs also noted that it is not uncommon to have to adjust (adapt) rapidly to dim lighting after flying in bright conditions.

Night vision was also important for one SME who recalled a time when he was trying to identify a submarine at night. Considering a submarine at night may look very similar to a sailboat, misidentifications do occur. As a result, sailboats have occasionally had sonobuoys dropped near or on them, due to pilots incorrectly identifying them as submarines.

The SMEs also reported the challenges associated with finding airport runway lights amongst surrounding bright city lights at night. They indicated that it is a difficult task to distinguish the runway lights within the myriad of additional city lights that may also be brighter than the runway lights. To mitigate this difficulty, the SMEs reported they look for patterns in city lights in order to identify an airport runway strip. Complicating this task though, is the fact that any one of the lights presumed to be a city light may actually be another aircraft flying directly in the flightpath of a pilot attempting to land their aircraft.

Several of the SMEs noted the visual difficulties associated with NVGs. Among them, they need to be focused carefully before use, the focus adjustment range is limited (2.0 D), the visual field is limited (reported to be 40 deg), the green monochrome display leaves colour after-effects (referred to as "pink eye") and it is very difficult to judge depth through the NVGs. The pilots also indicated that it is difficult to keep the cockpit in the field of view through NVGs, in order to maintain a spatial reference.

3.8 Depth Perception

3.8.1 Description

On dynamic tasks such as walking, driving a car, or flying a plane, depth information regarding the position of objects in relation to ones' current position (*egocentric localization*), as well as the location of objects relative to one another (*relative localization*), are critical. Depth judgments are based on information from each eye alone (monocular depth information) as well as the two eyes working together (binocular depth perception). Considerable monocular depth information can be acquired from the so-called "pictorial cues" that can be represented on a two-dimensional surface (e.g., a photo or painting). These include object overlap, shading and shadow, relative size, height in the field of view, texture gradient, linear perspective and aerial or atmospheric perspective. Monocular depth information can also be derived from dynamic cues such as accommodation and convergence, motion parallax (faster relative motion for near objects) and deletion and accretion (the rate at which, in passing, a close object covers or reveals a more distant surface).

Binocular depth perception (*stereopsis*) is based on a comparison of how the image information in the two eyes differs due to their lateral separation (about 63 mm centre-to-centre for the average human observer). This perspective induced image difference, referred to as "retinal disparity", is the basis for "stereo" viewing systems (e.g., the "Viewmaster"). The ability to appreciate such fine binocular perspective differences (as low as three to five sec of arc) is termed *stereoacuity*. Monocular eye conditions can impair stereoacuity and if present in early development (e.g., amblyopia, heterophoria, heterotropia), may even preclude its development. Since vision losses are more prevalent in the older eye, so too are failures of stereopsis (e.g., Wright & Wormald, 1992).

3.8.2 Literature Review

Good depth perception is critical to the pilot; when visual conditions are ambiguous (e.g., poor atmospheric conditions) or misleading regarding altitude, horizon, slope (Holmes, et al., 2003) or when information and vestibular information is in conflict (Regan, 1995), spatial disorientation can result. Fortunately, the redundancy of visually available distance and location information sources facilitates performance across most task conditions. For example, although NVGs appear to induce a transient loss of stereoscopic depth perception, depth perception based on monocular information is unimpaired (Sheehy & Wilkinson, 1989). For most jobs and tasks, stereopsis appears to be critical only when other sources of depth information are not available (Casson, 1995), or when viewing conditions are poor (Jones & Lee, 1981). Few occupations have a binocular vision requirement (Beard, Hisle, & Ahumada, 2002; Good, Weaver, & Augsberger, 1996) and there is reason to question its relevance as a visual standard for flying. Snyder and Lezotte (1993) found that attrition rates in the U.S. Air Force were not different for individuals with good or poor distance stereopsis. After a review of its theoretical and empirical bases, Diepgen (1993) concluded that there is not sufficient reason for having a stereopsis standard for pilots. Consistent with this view, the requirements for pilot entry to the CF identify a test that can be administered for stereoacuity (the Titmus), however, there is no standard or threshold (ASCC, 2003).

3.8.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual system in terms of depth perception. For example, interpreting the radar plot is a depth critical task. A radar plot may display four contacts on it, all at differing altitudes and the pilot must be able to resolve the true picture of the outside world with respect to the plot. In essence, the pilot must be able to view a two-dimensional radar display and mentally map this picture in three dimensions in order to establish situational awareness that is true to reality.

The SMEs also noted the importance of depth perception when landing an aircraft adjacent to obstacles and determining the distance to those obstacles. For example, the helicopter pilots must be aware of the clearance afforded from the helicopter rotor blades to surrounding objects. Another example illustrating the importance of depth perception is the task of formation flying; the ability to distinguish the distance between aircraft is a safety critical element of this piloting task. Further, depth judgment is more difficult in low contrast conditions and at night. While NVGs help the pilot to see in dim conditions, it is difficult to judge depth accurately through them and it can take a number of weeks to learn to estimate depth perception through NVGs. The SMEs also indicated that it is difficult to judge depth over uniform terrain and water, a problem for both landing and low-level flight. To avoid this, some rotary-wing pilots reported that when possible they increase altitude when flying over water.

3.9 Motion Perception

3.9.1 Description

Sensitivity to motion can be measured in a variety of ways, but none of them have been standardized for large-scale clinical application. One laboratory approach is to determine the minimum spatial displacement of a visual target that produces discriminable movement, a measure known as the *oscillatory motion displacement threshold* (OMDT). Investigators have also used random dot motion displays to study the minimum proportion of elements moving in a common direction that yields directional motion (i.e., the *coherence threshold*). Another measure, used in both lab and field studies, is to have observers estimate the time at which a moving target will arrive at a specified location or collide with another object. Field studies may also ask observers to estimate the velocity, acceleration and/or direction of a target vehicle or object.

There is compelling laboratory evidence of age-related declines in motion sensitivity as measured by OMDTs (Kline, Culham, Bartel & Lynk, 2001) and coherence thresholds (Trick & Silverman, 1991). A lab study by Andersen, Cisneros, Saidpour and Atchley (2000) had observers view displays simulating a 3-D environment with obstacles lying in the path of target motion. As target motion decelerated at a constant rate, the obstacle was blacked out. On some trials, the rate of deceleration would result in a “collision” with an obstacle, on others it would not. The proportion of judgments of a collision on no-collision trials was greater for older than younger observers. This led the authors to suggest that the elevated accident rates of older drivers might be due in part to an inability to detect collisions at high speeds. Deficits on such lab tasks, however, may not characterize aging effects on real-world judgments of speed.

Scialfa, Guzy, Leibowitz, Garvey and Tyrrell (1991) examined age differences in the magnitude estimations of velocity for automobiles traveling at speeds varying from 15-50 MPH (24-80 KPH). Young and old observers both tended to underestimate the speed of slow-moving vehicles and overestimate the speed of rapid ones, but the effect was less pronounced for older observers. The resulting psychophysical functions relating perceived speed to actual speed, suggested that older observers were less sensitive to relative changes in velocity, but that their absolute judgments of speed were more accurate than young observers. However, the implications of these findings regarding the effects of driver age on driving safety are unclear.

3.9.2 Literature Review

The accuracy of motion perception is affected by a range of situational variables, including the effects of motion adaptation, misattribution of the motion, poor visibility and the visibility of effective texture information from the terrain. When Stewart and Clark (1975) measured the effects of CRT-presented rotary motion on airline pilots' response speed to horizontal acceleration, reaction time increased directly with the duration of exposure to rotary motion. Gray and Regan (2000) studied the effect of adaptation to image expansion in a driving simulator overtaking task. After driving on a straight roadway, drivers initiated overtaking later on, in comparison to a similar period of driving through curved roadway, or viewing a static scene. The authors concluded that the difference was due to misestimating headway time caused by local adaptation of the looming detectors that signal motion in depth. They later suggested (Regan & Gray, 2001) that drivers should vary their direction of gaze during extended driving on straight empty roads, in order to reduce local motion adaptation due to retinal image expansion and thus reduce errors in judging time to collision. Perhaps similar advice would benefit pilots engaged in prolonged low-level flight.

Misattribution of the source of motion, (that occurs in a motion-depth illusion as based on the “far-anchor effect”), can also erode the accuracy of motion perception. Specifically, in limited viewing conditions, motion may be attributed to the further of two targets when only the near one is actually moving (Young, Mershon & Hicks, 2002). In a study with college student observers, Young et al. found that this illusion was not attenuated by fixational instructions, feedback, or the vertical on-screen separation of the targets. They noted the implications of problems in judging motion in depth for midair collisions and ground-incursion incidents when visibility is reduced. Similarly, after comparing the ability of pilots and non-pilots to make simulated night landing approaches, Mertens (1978) suggested that the visual illusions associated with the ineffectiveness of motion parallax in night conditions might be an important contributor to night approach problems.

The terrain and the ability to see it, appear to contribute importantly to a pilot’s judgment of speed, altitude and direction of motion in low-level flight and landing. Lintern and Liu (1991) found that the implicit specification of an on-screen horizon using texture contributed to a more accurate perception of simulated glide slope angle. Texture has also been found to affect simulated altitude control at higher speeds (Flach, Warren, Garness, Kelly, & Stanard, 1997). Flight over water appears to create special problems for pilots’ perception of self-motion. Ungs (1989) surveyed 267 U.S. Coast Guard helicopter pilots regarding the occurrence of illusory vection while flying over water in different sea and lighting conditions. The illusion was reported by over 92% of the pilots and almost 85% of them indicated that its likelihood was increased in dark conditions. They were also somewhat more likely to report the problem as worse over rough (about 46%) than smooth seas (about 38%).

The absence of a required motion sensitivity threshold for pilot entry into the CF is consistent with the lack of a clinically accepted standard for its measurement. Nor does such a standard seem feasible currently, given the wide range of different motion tasks, their broad susceptibility to contextual variables and high inter- (e.g., Otakeno, Matthews, Folio, Previc & Lessard, 2002) and intra-individual variability (e.g., Hong & Regan, 1989) in sensitivity to different aspects of motion.

3.9.3 Related Tasks

The SME discussion identified common pilot tasks that are challenging to the visual system in terms of motion perception. Consistent with Ungs (1989) findings of vision while flying over water, the helicopter pilots reported that the task of hovering in a stable position over a moving ship is difficult to perform. The difficulty lies in discerning how the aircraft is moving in relation to the ship and how the ship is moving in relation to the aircraft in order to maintain aircraft position. Motion perception is also a necessary visual function when detecting other air traffic in the sky, as it is the relative motion of other aircraft that first cues a pilot to their presence.

Motion perception is important within aircraft cockpits as well. Many lights in the cockpit will flicker or flash to indicate a warning to the pilot. However, these warning lights may or may not be in the direct field of view of the pilot. Another difficult visual task related to motion perception is the ability to detect whether or not helicopter main blades are rotating. When helicopter blades are rotating, they may be spinning so fast that it is difficult to discern whether they are in fact actually spinning (due to an optical illusion effect), making this a safety critical task.

3.10 Refractive Error and Optical Correction

3.10.1 Description

Four common types of refractive problems, *myopia*, *hyperopia*, *astigmatism*, and *presbyopia* can degrade the quality of vision. In myopia (nearsightedness), the eye's optic media are too strong relative to eyeball length. This causes images to be focused in front of the retina. A negative-sphere (concave) ophthalmic lens is prescribed to move the focal plane back to the retina and improve distance vision. In hyperopia (far-sightedness), the image plane is beyond the retina due to insufficient refractive power relative to eyeball length. A positive sphere (convex) corrective lens is used to add refractive power and bring near objects to better focus.

Astigmatism refers to unevenness of image focus, and is usually due to an irregular cornea - one shaped more like a football than a basketball. Such an eye has greater refractive power and greater visual clarity at some orientations than others. Astigmatism is labeled depending on the orientation at which it occurs. If refractive power is greater in the vertical plane (i.e., $90° \pm 25^0$), it is termed *with-the-rule*; if it is closer to the horizontal axis ($0° \pm 25^0$), it is termed *against-the-rule*. Eyes with greater focusing power between the vertical and horizontal axes are said to manifest *oblique* astigmatism. Astigmatism is corrected optically using a cylindrical lens of the appropriate power and axis.

Presbyopia is the progressive age-related loss of focusing (accommodative) power that leads to a steady recession of the near point of vision (see section 3.2.1 regarding the effects of presbyopia on near acuity). A positive sphere lens (e.g., reading glasses) or lens segment (e.g., bifocals or trifocals) can be used to compensate for the older eye's lost focusing capacity.

Refractive errors necessitating the use of corrective lenses are increasingly prevalent with increasing age. Wang, Klein, Klein, and Moss (1994) reported that far-sightedness (*hyperopia*) in excess of .5 diopters in the right-eye rose from about 22% in those 43 to 54 years to almost 69% among those 75 and older. The prevalence of nearsightedness (*myopia*) in excess of 0.5 diopters, declined from about 43% to 14%. Astigmatism is also more prevalent in the later years and is frequently accompanied by a change in axis. For example, Gudmundsdottir, Jonasson, Jonsson, Stefansson, Sasaki & Sasaki (2000) found that the prevalence of right eyes requiring ± .75 D or more of cylindrical lens correction increased markedly with age for both men and women. They observed a decline with age in the prevalence of with-the-rule astigmatism and a marked elevation in both against-the-rule and oblique astigmatism.

3.10.2 Literature Review

The importance of corrective eyewear is highlighted by the significant proportion of aviators in both military and civilian aviation that require visual correction. A sample of over 2,000 members of the U.S. Air Force found that almost 20% of pilots and approximately 50% of navigators were required to wear corrective lenses while flying (Provines, Woessner, Rahe, & Tredici, 1983). Similar levels were found in a later study of the records of over 5,000 active U.S. Air Force personnel (Miller, Woessner, Dennis, O'Neal & Green, 1990); 27.4% of pilots and 51.5% of navigators/weapons systems operators required corrective lenses. While myopia was the predominant refractive error, clinically significant astigmatism was also common (e.g., 33% of pilots). Among pilots who wore spectacles, more than 12% required bifocals. These findings contrast with those at the pilots' time of entry into the Air Force when emmetropia (no refractive error) and hyperopia were considerably more common. Based on a study of 1400 Israeli Air Force personnel, Froom, Biger, Erel, Davidson and Shochat (1992) concluded that the likelihood of a pilot requiring lens correction for myopia was greater if myopia was present in one eye at the time of entry into the Air Force.

The growing impact of age-related change in refractive error and ophthalmic lens use in aviation has been the topic of concern in several studies. In a 25-year prospective study of Japan Air Self Defense Personnel Force, Kikukawa, Yagura and Akamatsu (1999) found that from age 20 to 45, the proportion of participants requiring a distant visual correction increased from 15.8% to 37.1%. Interestingly, those with best acuity at entry showed a lower need for corrective lenses later on. The same benefit of high initial levels of uncorrected acuity has been recorded in the Royal Australian Air Force (RAAF). After surveying all RAAF personnel records, Mork and Watson (1993) concluded that the highly restrictive visual refraction standards for entry into RAAF aircrew training, relative to the USAF, were associated with a reduced prevalence of corrective lens usage. Further, as the mean age of the U.S. civilian pilot population increased to 39.8 years from 1971 to 1991, Nakagawara, Wood, and Montgomery (1995) found a 12% rise in the population with a near-vision restriction.

As the age of the pilot population increases, more problems associated with presbyopia and near-vision can be expected. Hyperopia and low amplitude of accommodation in pilots at age 20 appear to be risk factors for early presbyopia (Spierer & Shaley, 2003). After reviewing all the medical restriction data for civil aviators in the U.S. from 1976 to 2001, Nakagawara, Montgomery and Wood (2004) found that the increase in mean pilot age (from 36.8 to 42.3 years) was associated with a marked elevation in near-vision restrictions (13%), a rate more than double the increase (6%) found for distance vision. Noting that 92% of all medical restrictions as of 2001 were vision related, the authors noted the growing challenge in eye-care and visual correction for the aging aviatior community.

Generally, it appears that corrective lenses (contact lenses or spectacles) can be used safely and effectively in aviation. Several studies have shown that contact lenses provide effective vision correction for pilots (Bachman, 1990; Bickel & Barr, 1997; Polishuk, & Raz, 1975), even for critical and hazardous missions (Mittelman, Siegel, & Still, 1993).

Eyeglasses also appear to be visually effective for many tasks in the aviation environment. Still and Temme (1992) found that nighttime fixed-wing carrier landing scores were as good for U.S. Navy pilots who required spectacle correction as those who did not. Similarly, a study (Froom, Ribak, Burger & Gross, 1987) found that helicopter pilots with corrective lenses, or even minor uncorrected decreases in acuity, were not at increased risk for a serious accident.

However, not all studies have produced such positive findings regarding eyewear use for aircrew tasks and safety. Although a study of medically certified Category 1 Canadian commercial and airline pilots found that the accident rates of those with high refractive errors (+/- 5.7 D) were within the expected normal range, they were also higher than those having less extreme refractive errors (=/- 3.5 to +/- 5.6 D). Temme and Still (1991) found that navy pilots without eyeglasses were able to identify an “adversary” in combat maneuvers at a distance 20% greater than pilots who wore glasses.

Based on an analysis of the safety record data of civilian pilots, Nakagawara, Wood and Mongomery, (2002) found that contact lens use had contributed to five accidents and one incident. In a related study, the same authors (Nakagawara, Montgomery, & Wood, 2002) found evidence in the National Transportation Safety Board (NTSB) and Federal Aviation Administration (FAA) databases that ophthalmic devices were a contributing factor in 19 different mishaps. These included difficulties with lost or broken eyeglasses, problems with sunglasses, incompatibility with breathing equipment, or inappropriate prescriptions and contact lenses. Some, but of course not all, problems of this type can be alleviated through regular eye exams. Finally, a study of aircraft ejection events among U.S. Navy pilots (O’Connell & Markovits, 1995) found that all eyewear was lost in 37 of 46 cases. In all cases of eye-wear retention, the pilot’s visor was down, the oxygen mask in place and the helmet secured; a demonstration of the importance of enforcement of pilot adherence to standard operating procedures for these devices.

3.10.3 Related Tasks

The SMEs noted the need for pilots, including instructors, to have a good visual correction. Even if a pilot is flying with a co-pilot or a student pilot, it cannot be assumed that the individual is qualified to fly the aircraft alone or respond to an emergency. One SME noted that since NVGs cannot correct astigmatism, pilots with this problem require an optical correction. NVGs were also reported to be incompatible with progressive lenses making bifocals or trifocals a necessity for many older pilots. Problems with maintaining eyewear in place with severe G forces, the use of an oxygen mask, fogging of eyeglasses or the visor in hot conditions and contact lenses in dry environments, were also noted.

3.11 Refractive Error and Photorefractive Surgery

3.11.1 Description

Increasingly, refractive errors are treated using photorefractive surgery, LASIK (laser-assisted *in situ* keratomileusis) or PRK (photorefractive keratectomy) to permanently change the curvature of the cornea. In LASIK, a hinged flap is cut into the corneal surface. The flap is folded back, an excimer laser is used to vaporize some of the underlying stroma, and the flap is then smoothed back into place.

PRK is similar in that it is also performed with an excimer laser, but it is used to remove tissue from the very front surface of the cornea. In both types of surgery, the cornea is flattened for myopia, steepened for hyperopia, and smoothed for astigmatism. Although LASIK patients are likely to experience less discomfort and obtain good vision more quickly, surgeons may prefer PRK for patients with larger pupils or thin corneas. While most patients no longer need corrective lenses to carry out everyday visual tasks after LASIK or PRK, the optical aberrations induced by surgery can affect acuity and contrast sensitivity, particularly in dim light (Chisholm, Evans, Harlow, & Barbur, 2003; Schlote, Derse, Wannke, Bende, & Jean, 1999; Stern, 1999).

3.11.2 Literature Review

The development of photorefractive surgery techniques for correcting refractive errors has spawned concerns regarding their appropriateness for aviators (Markovits, 1993). These concerns include the structural stability of the eye as well as the effects on visual functioning post-surgery. As a result of such concerns, in some services such as the USN and USAF, pilots who have received photorefractive surgery are prohibited from service in combat jets (Levy, Zadok, & Barenboim, 2003).

Goodman, Johnson, Dillon, Edelhauser & Waller (2003) found that the healed LASIK flaps on rabbit eyes were not affected by a 9-G simulated ejection. Nor were any negative sequelae reported after an ejection by a U.S. Navy pilot 6 months after receiving PRK (Tanzer, Schallhorn, & Brown, 2000). Although one study (Levy, Zadok, & Barenboim, 2003) reports the case of an Israeli Air Force pilot who has performed numerous uneventful daytime flights in a combat aircraft, concerns regarding the impact of photorefractive surgery on nighttime vision and safety still remain.

Schallhorn, Blanton, Kaupp, Sutphin, Gordon, Goforth & Butler (1996) found that while susceptibility to disability glare was transient in active-duty military personnel, a prolonged reduction in the quality of vision at night was observed in one patient. Finding that PRK patients were much more susceptible to reductions of contrast sensitivity in glare, Schlote, Derse, Wannke, Bende and Jean (1999) concluded that the reduction of mesopic visual function is of special concern; particularly for those who, like pilots and professional drivers, have need of highly effective vision in low illumination conditions. There is also evidence, however, that low contrast acuity may be used to screen pilots for this problem (Chisholm, Evans, Harlow, & Barbur, 2003).

4 Results - Tasks

The goal of the task analysis in the SME session was to determine the essential tasks performed by CF pilots that are common and have a critical vision component. Essential tasks were identified and the relationship between the performance of the essential tasks and vision was evaluated.

In order to fulfill these requirements, the following steps were performed:

1. Document the essential visual tasks performed by CF pilots that are common across all aircraft types.
2. Determine the consequences of performing the tasks improperly and the frequency each task is performed; and
3. Select tasks that are feasible to simulate.

This procedure was followed to ensure that the proposed final vision standard will meet the requirements of the Canadian Human Rights Act.

4.1 Common Tasks Performed by CF Pilots

There are a wide range of tasks performed by the various CF pilots. For the current report, the list of tasks generated in the Vision Survey of CF Aircrew document (Heikens et al., 1999) for each type of aircraft was reviewed by the experimenters in order to focus on the most visually demanding and safety critical tasks in the SME session. The CF Vision Survey generated a list of the most demanding tasks in terms of vision for each of the aircraft types including: Tactical Helicopter, Search and Rescue Rotary Wing, Maritime Patrol Rotary Wing, Fixed Wing Transport, Maritime Patrol Fixed Wing, Fighter, Jet Trainer and Primary Trainer Rotary Wing.

The questionnaire in Appendix A lists the most visually demanding tasks as rated by the pilots of each aircraft type, according to the results in the CF Vision Survey. The questionnaire was then sent to the focus group SMEs prior to the discussion, in order to obtain additional information that may also influence pilot tasks. This provided an initiation point for the SME discussions and enabled the pilots to add or modify tasks as they deemed necessary.

During the SME session, it was reported that a number of the pilot tasks listed in the CF Vision Survey, and subsequently, listed in the questionnaire, were not currently performed. For example, the survey listed ‘Hovering’ and ‘Slinging’ as tasks that helicopter pilots perform; however, the SMEs indicated that these tasks are no longer conducted. Similarly, a number of tasks were omitted from the CF Vision Survey (and subsequently the questionnaire), that all pilots will be expected to perform in the future. This includes the use of NVGs, which will become more prevalent in the future for all night time piloting tasks. Further, during the discussion, the SMEs indicated that the visually demanding nature of many of their tasks is related to the requirement to constantly change visual focus between near, intermediate and far distance vision. This requirement is fatiguing to the eyes, regardless of the task being performed.

4.1.1 Vision Task Questionnaire Results

The results of the Vision Task Questionnaire are summarized below, by aircraft type:

- Tactical Helicopter: a number of the tasks listed in the questionnaire for Tactical helicopter are no longer performed by the pilots. For example, Nap of the Earth (NOE) Night Vision Goggle (NVG) flat terrain/rough terrain, formation night unaided and tactical approach NVG are not currently approved tasks. Advanced NVG limitations have been placed on NVG flying, including the requirement to stay 50 feet or above the highest obstacle when performing a low-level NVG task. The Tactical helicopter tasks were rated as either routine or non-routine, requiring near, intermediate and far vision, usually performed at night and may be performed by a newly recruited pilot (0-2 years of experience).
- Search and Rescue (SAR) Rotary Wing: A number of additional tasks were added to the SAR task list as a result of the questionnaire discussion during the focus group. These include Open water hoist (unaided day or night), Night hoist, and Night and day confined area operations. Overall, the SAR tasks were rated as either routine or non-routine, requiring near, intermediate and far vision, performed under all weather conditions and may be performed by a junior pilot with a minimum of 2-5 years of experience.
- Maritime Patrol Rotary Wing: The SMEs made changes to the tasks listed for these aircraft pilots as well. The tasks added include Sling at sea day/night and Water landing day/night. The tasks of approach/landing on a ship at night unaided in rough sea were rated as emergency tasks, as the SMEs indicated these tasks would usually be performed aided, hence, it would be an emergency if performed unaided. Other tasks were rated as either routine or non-routine, all requiring near, intermediate and far vision, performed under all weather conditions and may be performed by either a new recruit or a junior pilot.
- Fixed Wing Transport: The SMEs also added a number of tasks to the Fixed Wing list including tactical departure shallow/steep altitude, low level mountain flying and tactical arrivals from low/medium and high altitudes. It was reported that Low altitude parachute extraction NVG is a task no longer performed by pilots. The tasks were rated as either routine or non-routine, all requiring near, intermediate and far vision, performed under all weather conditions and performed by a junior pilot as a minimum.
- Maritime Patrol Fixed Wing (MPFW): The NVG tasks that were listed in the questionnaire are not performed by MPFW pilots, as reported in the SME session. Many of the tasks discussed that are performed by these pilots include a variation of either target or smoke detection in day/night conditions, calm/rough sea or forested terrain, and/or unaided. Many of the tasks were rated as non-routine, all requiring near, intermediate and far vision, performed under all weather conditions and performed by a junior pilot as a minimum.
- Fighter: The SME discussion indicated that target detection is also a common task performed by fighter pilots, however, this task must be performed while viewing through a Head up Display (HUD). The task may also be performed at

night and unaided. The task of low level flying is avoided in fighter aircraft and if this type of task is performed, it would be considered an emergency. Fighter tasks require near, intermediate and far vision, they may be performed under all weather conditions and may be performed by a new recruit (excluding the emergency task which would be performed by an intermediate pilot with five to ten years of experience).

- The questionnaire was not filled in by the SMEs for the Jet Trainer or the Primary Trainer Rotary Wing. However, these trainers were discussed at the SME session. The original scope of this project was to focus on conditions that pilots would be exposed to in training (relating to the entrance/recruitment vision standard for aircrew). However, the SME session revealed that new recruits are not exposed to some of the more challenging flight situations experienced by more senior pilots, thereby a vision standard based upon an entry-level task would not encompass the most difficult tasks later performed by pilots. Some of these tasks include NVG flying, night formation, hovering over a ship at night, and performance in severe environmental conditions.

4.1.2 SME Discussion

From the SME discussion and the vision questionnaire results, it was determined that a number of commonalities exist between the tasks performed in each aircraft type and that safety critical tasks have many similar vision demands as commonly performed, routine tasks.

It was concluded that the visual demands for each pilot task (regardless of aircraft type) exist on a continuum between high and low visual demands, depending upon a number of extraneous factors. These extraneous factors include the interior and exterior lighting conditions (good/poor), a vibrating cockpit, wearing laser eye protection or NVGs, a variety of distances challenging the visual system (near, intermediate, far and constantly transitioning between these three distances) and a variety of environmental conditions (night, snow, rain, dusk, dawn, fog, etc). Each of these factors may work alone or in combination to affect the visual demands of any pilot task. The following is a list generated from the SME discussion of tasks performed by <u>all</u> pilots regardless of airplane type.

- Reading VFR maps, contour maps, and approach plates
- Interaction with and comprehension of CRT instrumentation, the weather radar display and the flight management system
- Target/object detection and identification
- Aircraft landing and take-off
- Perceiving and responding to cockpit warning lights
- Detecting other aircraft and/or birds in the peripheral field of view
- Determining attitude (pitch, roll and yaw) of the aircraft
- Flying directly into the sun or flying with the sun directly behind the aircraft
- Distinguishing differences between colour coded items, both inside and outside of the cockpit
- Determining clearance distance between the aircraft and surrounding objects

- Movement detection from within the aircraft cockpit (e.g., flashing warning lights)
- Night instrument approach landing
- Continuous transitioning between near and far viewing (cockpit instrumentation to exterior environment)
- Low-level flying over various terrain
- Fast visual accommodation from bright light to low light and vice versa
- Reading emergency checklists while flying and responding appropriately
- Emergency Autorotation training (although only for rotary wing pilots)

These tasks may be influenced by any one of the extraneous factors previously listed above.

4.2 Consequences of Improper Performance

With each of these tasks, there are consequences related to improper performance ranging from mild (mistake determined and correction performed) to severe (accident resulting in death or destruction of property). The SMEs indicated that all of the common tasks listed above are associated with flying, and therefore, if performed improperly can lead to severe consequences.

4.3 Task Scenarios

The SME discussion enabled the experimenters to ascertain visual acuity demand commonalities across all aircraft types. This is important for the purpose of the visual acuity test in order to establish a bona fide entrance standard that may be applicable to all CF pilot recruits, regardless of the type of aircraft eventually flown. Considering visual acuity can be further decomposed into near and far acuity, both of these parameters should be simulated and tested to establish the entrance standard. Again, the scenarios must involve visual acuity functions that are applicable to all aircraft.

4.3.1 Near Visual Acuity Task

One common and critical near visual acuity task that all CF pilots must perform (regardless of aircraft type) is reading and understanding approach plates in order to land an aircraft at night. Again, this task is common, yet visually demanding and correct performance is critical. The SMEs discussed extraneous factors that may be present to make this task more difficult including:

- Poor interior lighting conditions: For example, the Sea King has red interior cockpit lighting and the interior lights used to view approach plates at night are generally very dim in most cockpits;
- Poor environmental visibility: This task must be performed in any kind of night time environmental conditions including bright sunset, snowstorm, thunderstorm, thick cloud cover, etc. The SMEs indicated that this task is especially difficult at night because of the use of cockpit lighting which inhibits night vision adaptation and renders visibility outside of the cockpit extremely difficult;

- Vibrating cockpit: This task is made further challenging by the vibration of the cockpit. Again, the amount of vibration will be dependant upon the weather conditions experienced. For example, high winds will contribute to a vibrating cockpit which will make this focused reading task extremely difficult;
- Vision Enhancers: Pilots may be expected to perform this task while wearing either laser eye protection or NVGs. Again, this increases the task difficulty, as the approach plates are colour coded and NVGs inhibit colour visibility and distinction. NVGs also inhibit the visible FOV available to the pilot and make the transition from near, intermediate and far vision very difficult (pilots have to look down below the NVG to see near objects);
- Vision Transition: Pilots must be able to look at their cockpit instrumentation (near and colour vision), to their immediate surroundings (intermediate vision), to distant objects (far vision) for detection and identification purposes. The constant transition between these distances is a challenge to the visual system;
- Combination: Reading and understanding approach plates is a commonly performed pilot task across all aircraft. The combination of any or all of the above listed extraneous factors can challenge the visual system and may render the task of approach plate reading extremely difficult. Any of these extraneous factors may work alone or in combination to challenge the visual system of any pilot, in any type of aircraft, at any time.

As a result, it was decided that the task of reading and understanding approach plates in order to land an aircraft at night was highly suitable for testing the near visual acuity entry requirement of pilots.

4.3.2 Far Visual Acuity Task

One common and critical far acuity task that all CF pilots must perform frequently (regardless of aircraft type) is target identification. Again, this task is common, yet visually demanding and correct performance is critical. The number and type of targets that pilots must identify are numerous, including ship identification lettering, search and rescue for people stranded in the sea, birds in the sky, other aircraft in the sky, ground target vehicles, crash sites and runway lights. One far acuity (target identification) task that is common across all aircraft is visual identification of targets associated with aircraft landing and approach for landing. This task is common for all aircraft types, although rotary wing pilots may have more reaction time (longer approach time, same angle). This task will involve air to ground reconnaissance of the landing area. There is also an element of criticality associated with this task, due to the limited time to make decisions/act before the situation becomes a potential emergency. Further, if the pilot misses the runway, the procedures for a ‘missed runway’ will have to be followed (which includes reading the approach plates and determining the emergency procedure when a runway has been overshot). The SMEs discussed extraneous factors that may be present to make this task more difficult including:

- Poor environmental visibility: This task must be performed in any kind of environmental conditions including bright sunshine, snowstorm, thunderstorm, thick cloud cover, night etc;

- Vibrating cockpit: This task is made further challenging by the vibration of the cockpit. Again, the amount of vibration will be dependant upon the weather conditions experienced. For example, high winds will contribute to a vibrating cockpit which will make a target identification task extremely difficult;
- Vision Enhancers: Pilots may be expected to perform this task while wearing either laser eye protection or NVGs. Again, this increases the task difficulty, as NVGs inhibit colour visibility and distinction. NVGs also inhibit the visible FOV available to the pilot and increase the difficulty in transitioning between near, intermediate and far vision (pilots have to look down below the NVG to see near objects);
- Vision Transition: Pilots must be able to look at their cockpit instrumentation (near and colour vision), to their immediate surroundings (intermediate vision), to distant objects (far vision) during a target identification task. The constant transition between these distances is also challenging to the visual system;
- Combination: The combination of all of the above listed extraneous factors can challenge the visual system and render the task of target identification during landing/approach extremely difficult. Any of these extraneous factors may work alone or in combination to challenge the visual system of any pilot, in any type of aircraft, at any time.

As a result, it was decided that the task of target identification during landing/approach was highly suitable for testing the far visual acuity entrance requirement of pilots.

5 Results - Proposed Test Scenarios

Based on results of the literature review, questionnaire and SME discussion, a high-level experimental plan for testing the selected near and far visual acuity tasks has been developed. This plan involves the conduct of two experimental scenarios designed to obtain objective evidence of the relationship between visual acuity level and task performance.

As for any visually demanding occupation, it is axiomatic that vision standards for aircrew should be based on a comprehensive evaluation of all the visual demands of operational tasks across the full range of viewing conditions under which they are actually carried out. The absence of the resources and time required to advance such an ideal research model, however, mandate the use of more cost-effective simulation approaches that are based on careful analyses of the most visually demanding tasks and conditions that occur operationally.

The level of resources available to support the research, in combination with client priorities, will determine which one of three possible levels of fidelity to operating conditions is selected: 1. Real world tasks, 2. High-fidelity simulation using CF flight simulators, or 3. Low-fidelity simulation conducted in a laboratory. For both the high- and low-fidelity task simulations, a systematic effort will be made to ensure that the relevant task variables are representative of actual operational conditions (e.g., contrast levels, size scale, etc.).

High- and low- fidelity flight simulators are proposed in order to allow standardization of lighting levels, environmental conditions and to control the size and distance of test items. This will also allow control of luminance and contrast levels so that any differences between the testing time of day will not likely have a confounding effect due to the randomization of the conditions.

Of the simulation options available, high-fidelity simulation using CF flight simulators would be preferred and in fact, may be feasible for evaluating the near-acuity demands of extracting critical information from landing approach plates (see description of Near Visual Acuity Test Scenario below) under realistic cockpit conditions (e.g., lighting, environmental complexity, competing task demands, etc.). Considering the complexity, costs and perhaps limited availability of CF flight simulators, however, the Far Visual Acuity Test Scenario (described below) may need to be conducted using a lab-based low-fidelity simulation. It is critical that such an effort be initiated with an understanding of the costs, benefits and anticipated limitations of such simulation research.

Investigation into realistic environmental conditions will be conducted to determine if experimentation can be conducted in field conditions. However, consideration must be given to the tradeoff between conducting task simulations in realistic environments and having complete control over the experimental environment.

5.1 Lab-Based Simulation

The advantages of a Lab-Based Simulation are listed below:

1.) Fast, cost-effective "scenario" development.
2.) Testing in a safe, highly stable, constantly accessible environment.
3.) Precise control over viewing conditions, relevant target and background visual parameters (e.g., stimulus size, luminance, contrast, colour, location, rate of motion), and observer variables (e.g., visual health, light adaptation state, spatial vision, colour vision).
4.) The capacity to relate observer visual characteristics (e.g., gaze direction, optical correction, visual field, acuity, contrast sensitivity) precisely to on-screen display elements (size, colour, field location).

The limitations of a Lab-Based Simulation Approach include the following:

1.) Testing with computer displays does not necessitate multiple-task integration characteristic of simulator and real-world flying tasks.
2.) The "safe" lab environment is not amenable to the study of realistic pilot decision-making and risk-taking.
3.) Real-world weather conditions (rain, fog) as well as many adverse viewing conditions cannot be represented adequately.
4.) True 3-D (i.e., binocular or stereopsis) depth information is not available in conventional monitor displays; they provide only monocular pictorial and relative motion monocular cues to depth.

To maximize the generalizability of lab findings to operational tasks and conditions, a systematic evaluation of the pilot visual tasks and the range of field conditions under which they are likely to be carried out should be conducted. This will include detailed task analyses to supplement the information provided by the review of the research literature and the many insights provided by the SMEs. Once the critical task demands have been determined, the stimulus dimensions (e.g., size, luminance, contrast, colour) and environmental variables (e.g., lighting, glare, competing tasks, task allocation in single-pilot vs. multi-crew cockpits) likely to be encountered operationally will be measured. To facilitate the subsequent development of the specific experimental plan, another SME session is recommended to verify the simulation scenario(s) "realism", likelihood and scale.

5.2 Near Visual Acuity Test Scenario

All aircrew regardless of aircraft type of or mission, depend critically on the information provided by approach plates in landing. Thus, measures of the ability to extract information from them as a function of varied acuity and lighting is proposed for the near task. Although this study could be conducted in the lab using lighting levels similar to those in a cockpit, testing in a CF flight simulator would provide a more realistic environment for this (in fact, given differences in rotary and fixed-wing operations and the wide variation in cockpit lighting levels and spectral characteristics, it would be preferable to conduct the near acuity scenario in more than one CF flight simulator).

5.2.1 Participants

To address the growing concern regarding age-related differences on visual function and aircrew task performance, two groups of 12 trained CF pilots will participate in the study: a young group aged 20 to 35 years, and an older group aged 35 to 49 years. (If there are not sufficient numbers of pilots to complete the two age groups, as wide an age range as possible will be recruited to allow regression analyses on pilot age.) Participants will be screened for general and visual health as well as presenting optical prescription (if any). Optimal near (40 cm) and far (6 m) ophthalmic correction and acuity will then be determined for comparison of the effects of optically-degraded acuity with the best-corrected levels. Pilots with levels of refractive error acceptable to the CF will be included, but will have no prior history of eye surgery.

5.2.2 Method

A vision questionnaire will first be administered to the participants to determine their use of glasses and/or contact lenses while on duty and any visual problems that they have encountered in flying. They will then be tested for both high- and low-contrast (Small Letter Contrast Test) near acuity (40 cm) and then refracted to best near acuity. The levels of positive sphere blur required to induce 6/9, 6/12 and 6/18 near acuity will then be determined

Participants' ability (accuracy and latency) to find pre-cued critical target details of 3 sizes (small, medium and large-bold) on the approach plates will be determined at 40 cm for Best, 6/9, 6/12 and 6/18 near acuity levels for daylight, dusk/dawn and night cockpit lighting levels. The testing order will be counterbalanced.

5.2.3 Results

Response accuracy and latency data will be analyzed initially using Age (2) X Acuity (4) X Lighting (3) X Plate Detail (3) split-plot ANOVAs. The "predictive" relationships between optical correction, visual problems while flying, high-contrast acuity and low-contrast acuity will be determined across and within age groups for the different lighting conditions using correlation techniques.

5.3 Far Visual Acuity Test Scenario

To be representative of the visual demands faced by pilots on different missions and flying different aircraft types, the far task will examine the ability to detect and identify surface objects (e.g., runway hazards, obstacles to ground landing or SAR over water) in daylight and dusk/dawn lighting as a function of participant acuity. Although testing in a CF flight simulator would be more realistic and thus preferable, a lab-based simulation may be the only feasible alternative. The method proposed below is based on this assumption.

5.3.1 Participants

Except for testing high- and low-contrast acuity at 2 m, rather than 40 cm, the participants, their background and visual screening will be the same as described in the Near Visual Acuity scenario above.

5.3.2 Method

5.3.2.1 Apparatus and Materials

Target stimuli will be five realistic objects of similar size, varied across three levels of luminance contrast relative to the background scene in which they appear. They will be presented at 2 m on a high-resolution cinema (30-in) display under the control of an Apple G5 dual-processor computer. The target stimuli will appear on realistic digitally photographed background day and dusk/dawn scenes (e.g., runways, grass, water, etc.).

5.3.2.2 Procedure

To simulate a landing approach, scene size will be increased in small discrete steps (although a continuous dynamic looming scene would be more realistic, it would confound the effects of response speed and visual acuity and also make separate measures of target detection and identification impossible.). The participants' task will be to determine if any of the five pre-cued target hazards is present (target-present trials) in the defined "landing area", or not (target-absent trials) and then, as scene size increases further, to identify it. The size at which the presence (i.e., location) or absence of a target is correctly detected as well as the size at which it is correctly identified will both be recorded. Hazard detection and identification will be determined for four acuity levels at the 2-m test distance: Best, 6/9, 6/12, 6/18 and 6/24 in simulated day and dusk/dawn conditions. The testing order will be counterbalanced.

5.3.3 Results

Detection and identification thresholds data will be analyzed separately using an Age (2) X Acuity (5) X Lighting (2) X Target Contrast (3) split-plot ANOVAs. Correlation techniques will be used to establish the relationships between optical correction, visual problems while flying, high-contrast acuity and low-contrast acuity (across and within age groups) under the different lighting conditions for both target detection and identification and also the relationships between the tow measures in the different conditions.

5.4 General Experimental Plan

The general experimental plan is described in the sections below.

5.4.1 Clarification of Tasks

To facilitate the development of a detailed experimental plan, another SME session is recommended to:

- Verify the realism of the simulation scenarios,
- Subdivide the scenarios into component tasks,
- Validate the task list,
- Prioritize the pilot tasks in terms of mission criticality and pilot safety,
- Review and characterize the visual demands of critical pilot tasks, and
- Review emergency pilot procedures and critical incidents.

As stated previously, a vision questionnaire will also be administered to gather information related to the use of glasses and/or contact lenses while on duty. The purpose of determining the use of glasses and contact lens use is to acquire information regarding the current practices of pilots with less than 6/6 vision.

5.4.2 Randomizing Conditions

Experiments will be within-subjects randomized designs. The primary independent variables will be the levels of simulated visual acuity. The data gathered will allow a determination of the utility of the current CF high-contrast acuity standard for assessing near and far performance under varied “real-world” lighting levels. The proposed experimental plan will also allow a comparison of the predictive value of high- and low-contrast acuity tests in different lighting conditions.

Conditions will be randomized across trials so that a number of participants will be tested with the best visual acuity condition on the first trial while others will be tested with the worst visual acuity condition on the first trial. Care will be taken to ensure the test order of the conditions and the presence and location of specific target items will be evenly distributed across participants in order to minimize learning effects.

6 Discussion

Vision standards are critical to the effective and safe conduct of many tasks and this is particularly evident for many of the tasks involved in flight operations. Good vision is a vital requirement for mission success in many piloting tasks. As indicated in other sections of this report, there are a number of visual functions that may be considered in determining an appropriate vision standard. The original scope of this study focused on visual acuity, both near and far, and development of an uncorrected visual acuity standard for CF pilots. These aspects have been investigated with respect to developing a vision standard, while also giving consideration to other visual functions, and the adoption of a corrected vision standard.

6.1 Visual Acuity

Review of the literature revealed no studies or evaluations that supported or explained the origin of any of the present CF Aircrew visual acuity standards. Many vision standards appear to be based on expert opinion rather than job task analysis and empirical testing. Vision standards should be based on a demonstration that a certain level of acuity is actually needed to perform essential tasks safely and effectively.

6.1.1 Near Acuity Vision Standard

The proposed experimental task for near acuity is the ability to extract information from approach plates as a function of varied acuity and lighting. All aircrew, regardless of aircraft type or mission, depend critically on the information provided by approach plates in landing. No literature is available to substantiate the borrowing of near acuity vision standards from other occupations or countries. However, a few papers indicate that a near acuity occupational vision standard for pilots might be empirically derived. As described in the literature review, two empirical studies experimentally evaluated the minimal uncorrected visual acuity requirement for military aircrew and air control personnel. Mann and Hovis. (1996) highlighted that a major decrement in pilot performance during an IFR approach was the inability to read approach charts, maps and radio settings at acuity below .50 logMar (about 3 minarc or 16/50). This finding lends support to the selection of reading approach plates during landing as a critical pilot task and demonstrated performance degradation related to optical blur. However, these measures are not sufficient to set acceptable levels of near visual acuity because they were not intended to empirically justify a vision standard for military pilots. The proposed experimental plan will extend the previous research to investigate the effect of varying the size of information on the approach plates, as well as integration of high- and low-contrast conditions.

6.1.2 Far Acuity Vision Standard

The proposed experimental task for far acuity is the ability to detect and identify surface objects (e.g., runway hazards, obstacles to ground landing, or SAR over water) in daylight and dusk/dawn lighting as a function of participant acuity. No literature is available to substantiate the borrowing of vision standards from other occupations or countries. However, as described in the literature review, there is some indication that for many occupations, any degradation of visual acuity below 20/20 is associated with degraded performance in resolving fine detail at distance. Even small reductions in acuity have been shown to impair performance on detection tasks. It is unclear if tasks from other occupations suitably overlap with those of a CF pilot to substantiate a far acuity vision standard. Given that pilot-related detection tasks are conducted from a unique perspective (e.g. from air-to-ground rather than ground-to-ground) and may have different temporal considerations given a shorter exposure time (related to a high travel speed of aircraft), it would be unacceptable to borrow vision standards from other occupations.

The experimental approach proposed in this study is intended to extend the research by better defining the relationship between visual acuity and the distances required for safe and effective hazard detection and identification. Detection tasks and identification tasks will be investigated separately. Detection tasks involve many visual functions whereas identification relies more heavily on visual acuity. Separation of detection and identification tasks will more clearly characterize the visual acuity required to identify items at different distances. Characterizing the relationship between distance and visual acuity for the selected pilot related task will facilitate a determination of the necessary visual acuity given real-world distances experienced by CF pilots for target identification.

6.2 Potential Visual Functions to Consider in a Vision Standard

While the focus of this study was on visual acuity, using visual acuity as the sole measure to test vision may be too restrictive. Other visual functions may be useful in developing a standard that is more comprehensive by considering other visual parameters that affect task performance. Studies with pilots conducted in simulators and in field trials have shown that acuity alone is not an absolute indicator of actual task performance (Ginsburg *et al.*, 1982; Ginsburg, *et al.*, 1983). Regardless of these findings, visual acuity is still used as the primary indicator as to whether or not a person can see well enough to drive or pilot vehicles safely.

Other components of visual function, their associated diagnostic tests, and levels appropriate to flight operations were investigated in this study. Visual functions investigated included contrast sensitivity, visual fields, glare sensitivity, colour vision, night vision, depth perception, and motion perception. The literature reviews suggest that other visual functions may be as good or better discriminators of visual capability than visual acuity. For example, contrast sensitivity is not traditionally included in occupational vision standards, yet it has been found to be a better predictor of target detection and recognition than standard visual acuity measures for pilot’s attempting to detect ground-to-air targets in field studies (Ginsburg *et al.*, 1983) and in simulators (Ginsburg *et al.*, 1982).

Although there are many potential measures of visual function, there is no evidence at this time to suggest that any visual function is more valid than visual acuity for assessing pilot task performance. The recommended experimental protocols of this study include manipulation of contrast and lighting to provide additional insight into other visual functions that warrant consideration in developing a vision standard for CF pilots.

6.3 Adoption of a Corrected Visual Acuity Standard

Consideration should be given to adopt a *corrected* visual acuity standard. CF policy is to recruit candidates based upon an uncorrected visual acuity standard, yet many intermediate and senior level pilots currently rely upon vision correction. Because there are few difficulties in correcting to a high visual acuity, adopting a corrected visual acuity standard would facilitate a greater pool of candidates. In addition, most aviation governing bodies, such as the FAA, no longer require a specific uncorrected visual acuity (Beard et al., 2002). Refractive errors necessitating the use of corrective lenses are increasingly prevalent with increasing age. Because the Canadian Forces is recruiting older, more experienced pilots, a visual testing protocol designed to predict professional aircrew task performance must recognize that a visual measure may be of little relevance for younger eyes, yet may be critical in discerning problems in older eyes. Age-related visual acuity test measures should also consider the extent to which a measure will be valid for its requisite "predictive term" (i.e., time to next mandated test). A re-test interval that is appropriate for young observers may be too protracted for a faster changing older eye. The likelihood of age-related changes in refractive error, an older recruiting age, and the probable requirement for visual correction with age, highlight a need to consider the recognition of a corrected visual acuity standard.

Aspects of refractive error and photorefractive surgery were also investigated because consideration of candidates with corrective eye surgery into the CF pilot occupation would have a bearing on the visual acuity standard. Currently, personnel with corrective eye surgery are not eligible for entry into the CF pilot occupation. Concerns include the structural stability of the eye as well as the effects on visual functioning post-surgery.

Several studies have shown that corrective lenses can be used safely and effectively in aviation. SME discussions indicated that pilots requiring vision correction can carry spare glasses or they may fly with another pilot who can take over if the need arises (with the exception of fighter pilots). However, there is some evidence that corrected lenses contribute to a higher incidence of accidents, reduce identification capability in combat maneuvers, and contribute to aviation mishaps. SMEs did recall incidents that occurred as a result of wearing glasses: pilots experienced sweat dripping down their glasses, or their glasses became foggy. It is unclear whether these problems are significant enough to warrant an uncorrected vision standard.

7 Conclusion and Recommendations

In order to perform the simulation experiments proposed in this report, a number of action items must be performed. These include, but are not limited to:

- Determine a suitable simulation (or real-world) test bed for performing the experiments. This requires a review of the capabilities of the current flight simulation trainers and research platforms available in the Canadian Forces. Low-fidelity simulations, including laboratory based systems, and real-world test beds will also be investigated. Considerations will be given to cost, schedule and quality constraints.
- Measurement of stimulus dimension and environmental variables likely to be encountered operationally.
- Determine the feasibility and timeframe associated with developing the simulator software and hardware changes that will be required to perform the experiments.
- Verify the tasks and associated visual metrics with SMEs.
- Develop an experimental protocol for evaluating the simulation tests and obtain Human Ethics Committee approval. This includes identification of additional experimental plan details, development of an experimental introductory form, development of a participant information sheet, and development of a vision assessment form.
- Determine the suitable population for participating in the experiments based upon age, experience, gender, aircraft type flown, etc.
- Conduct, administer and validate the visual function tests required for a sample of aircrew in order to ascertain their acceptance for participating in the experiments.
- Revise and extend this report to include a description of the above points, the experimental design, the results and a recommendation for a vision standard for CF aircrew.
- Present the findings of the near and far visual acuity experiments.

These items will be conducted as part of the project contract extension.

The systematic and comprehensive approach proposed in this report will help to ensure that the Canadian Human Rights Commission finds the resulting vision standard for aircrew to be both reasonable and acceptable. The standard will ensure competent and safe performance of tasks required by CF pilots and it will be fair, by not unnecessarily excluding qualified candidates.

8 Appendix A- Vision Task Questionnaire

See attached questionnaire.

Vision Task Questionnaire

Name: ____

Position Title:_______________________________________

Type of aircraft flown (list aircraft most commonly flown first, followed by all other aircraft you have flying experience with):

1. ______________________________ 2. ___________________________________

3. _______________________________ 4. ___________________________________

5. ________________________________ 6. ____________________________________

Type	Vision Requirement	Environment	Experience Level
1 = Routine 2 = Non-Routine 3 = Emergency	1= Near vision 2= Intermediate vision 3= Far vision 4= Variable vision Requirements	1 = Bright Sunshine 2 = Rain 3 = Fog 4 = Snow 5 = Bright Sunshine + Ground Snow 6 = Night 7 = Dusk/Dawn	1 =New recruit (0-2 years of experience) 2 = Junior pilot (2-5 years of experience) 3 = Intermediate pilot (5-10 years of experience) 4 = Senior pilot (10 + years of experience)

OCCUPATIONAL TASKS (Grouped by Aircraft Type)	What type of task is this? **(1, 2, 3)**	What is the vision requirement for performing this task? **(1, 2, 3, 4)**	What environmental conditions is the task performed under? **(1, 2, 3, 4, 5, 6, 7)**	What is the LOWEST experience level required to perform these tasks? **(1, 2, 3, 4)**
Tactical Helicopter				
NOE NVG flat terrain				
VFR night unaided rough terrain				
NOE NVG rough terrain				
Formation night unaided				
Formation NVG				
Tactical approach NVG				
Glide path approach night unaided single light				
Hover NVG water				
Target detection day forested area				
Target detection night unaided open field				
Target detection night unaided forested area				
Smoke detection night unaided open field				
Smoke detection night unaided forested area				
Tactical approach NVG				
Hover night unaided flat terrain				
Hover NVG flat terrain				

OCCUPATIONAL TASKS (Grouped by Aircraft Type)	What type of task is this? **(1, 2, 3)**	What is the vision requirement for performing this task? **(1, 2, 3, 4)**	What environmental conditions is the task performed under? **(1, 2, 3, 4, 5, 6, 7)**	What is the LOWEST experience level required to perform these tasks? **(1, 2, 3, 4)**
S&R Rotary Wing				
Hover NVG water				
Sling NVG				
Target detection NVG rough water				
Smoke detection NVG forested area				
Smoke detection NVG rough water				
Formation night unaided				
Glide path approach night unaided single light				
VFR night unaided rough terrain				
Target detection day rough water				
Target detection night unaided open field				
Target detection night unaided forested area				
NVG rough terrain				

OCCUPATIONAL TASKS (Grouped by Aircraft Type)	What type of task is this? **(1, 2, 3)**	What is the vision requirement for performing this task? **(1, 2, 3, 4)**	What environmental conditions is the task performed under? **(1, 2, 3, 4, 5, 6, 7)**	What is the LOWEST experience level required to perform these tasks? **(1, 2, 3, 4)**
Maritime Patrol Rotary Wing				
VFR night unaided low level rough sea				
Approach night unaided ship rough sea				
Landing night unaided ship rough sea				
VFR night unaided low level calm sea				
Approach night unaided ship calm sea				
Approach NVG ship rough sea				
Hover night unaided calm sea				
Hover night unaided rough sea				
Target detection night unaided calm sea				
Target detection night unaided rough sea				
Smoke detection night unaided rough sea				
Ship identification day by light bad weather				
Ship identification night by light good weather				
Ship identification night by light bad weather				
Sling NVG				
NVG calm sea/rough sea				
NVG low level calm sea/rough sea				

OCCUPATIONAL TASKS **(Grouped by Aircraft Type)**	What type of task is this? **(1, 2, 3)**	What is the vision requirement for performing this task? **(1, 2, 3, 4)**	What environmental conditions is the task performed under? **(1, 2, 3, 4, 5, 6, 7)**	What is the LOWEST experience level required to perform these tasks? **(1, 2, 3, 4)**
Fixed Wing Transport				
Air refueling night unaided				
Formation night unaided				
Low altitude parachute extraction NVG				

OCCUPATIONAL TASKS **(Grouped by Aircraft Type)**	What type of task is this? **(1, 2, 3)**	What is the vision requirement for performing this task? **(1, 2, 3, 4)**	What environmental conditions is the task performed under? **(1, 2, 3, 4, 5, 6, 7)**	What is the LOWEST experience level required to perform these tasks? **(1, 2, 3, 4)**
Maritime Patrol Fixed Wing				
NVG rough sea				
Smoke detection NVG rough sea				
NVG calm sea				
Smoke detection night unaided rough sea				
Smoke detection NVG calm sea				
VFR night unaided low level calm sea				
VFR night unaided low level rough sea				
Target detection night unaided rough sea				
Target detection NVG calm sea				
Target detection NVG rough sea				
Smoke detection day rough sea				

OCCUPATIONAL TASKS **(Grouped by Aircraft Type)**	What type of task is this? **(1, 2, 3)**	What is the vision requirement for performing this task? **(1, 2, 3, 4)**	What environmental conditions is the task performed under? **(1, 2, 3, 4, 5, 6, 7)**	What is the LOWEST experience level required to perform these tasks? **(1, 2, 3, 4)**
Fighter				
NVG low level rough terrain				
Target detection air/ground through HUD night unaided				
Jet Trainer				
Formation night unaided				
Primary Trainer Rotary Wing				
Glide path approach night unaided single light				

9 Appendix B – Acronyms

ARM	Age-Related Maculopathy
ASCC	Air Standardization Coordination Committee
BAT	Brightness Acuity Tester
BCVA	Best Corrected Visual Acuity
BFOR	Bona Fide Occupational Requirements
BVA	Best Visual Acuity
CF	Canadian Forces
CS	Contrast Sensitivity
CSF	Contrast Sensitivity Function
DAR	Dark Adaptation Rate
DRDC	Defence Research and Development Canada
FAA	Federal Aviation Administration
FACT	Functional Acuity Contrast Test
FALANT	Farnsworth Lantern Test
FOV	Field of Vision
G&A	Greenley & Associates
HUD	Head up Display
IFR	Instrument-Flight-Rules
LASIK	Laser-Assisted *in situ K*eratomileusis
MPFW	Maritime Patrol Fixed Wing
NOE	Nap of the Earth
NTSB	National Transportation Safety Board
NVG	Night Vision Goggles
OMDT	Oscillatory Motion Displacement Threshold
PIP	Pseudoisochromatic Plate
PRK	Photorefractive Keratectomy
RAAF	Royal Australian Air Force
SAR	Search and Rescue
SLCT	Small Letter Contrast Test
SME	Subject Matter Expert
SRT	Scotopic Retinal Threshold
UCVA	Uncorrected Visual Acuity
UFOV	Useful Field of View
USA	United States Army
USAF	United States Air Force
USMC	United States Marine Corps
USN	United States Navy
VCTS	Vistech Contrast Testing System
VF	Visual Field
VFR	Visual Flight Rules

10 Appendix C – References

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(U) This report documents a study investigating the Canadian Forces (CF) aircrew entrance vision standard. A literature review was conducted to identify a method for establishing bona fide occupational requirements and validated standards for aircrew related visual functions. A protocol for establishing and validating an occupationally based visual acuity standard for the CF pilot occupation was selected. Tasks that have critical visual acuity functions were identified based on data obtained through questionnaires and a focus group session. The study proposes potential task simulations that accurately reflect critical aircrew tasks and an experimental plan to establish vision standards.

(U) Ce rapport présente une étude portant sur la norme visuelle fixée pour le personnel navigant au niveau d'entrée en fonction des Forces canadiennes. Une revue de la littérature visant à trouver une méthode pour établir des exigences professionnelles justifiées et des normes validées pour les fonctions visuelles du personnel navigant a été menée. Un protocole d'établissement et de validation d'une norme d'acuité visuelle pour la profession de pilote des FC a été choisi. Les tâches comportant des fonctions essentielles liées à l'acuité visuelle ont été définies à partir de données tirées de questionnaires et d'une séance de discussion en groupe. L'étude propose des simulations de tâches qui reflètent avec exactitude les tâches essentielles du personnel navigant et un plan expérimental de fixation des normes visuelles.

14. KEYWORDS, DESCRIPTORS or IDENTIFIERS (Technically meaningful terms or short phrases that characterize a document and could be helpful in cataloguing the document. They should be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location may also be included. If possible keywords should be selected from a published thesaurus, e.g. Thesaurus of Engineering and Scientific Terms (TEST) and that thesaurus identified. If it is not possible to select indexing terms which are Unclassified, the classification of each should be indicated as with the title.)

(U) Canadian Forces; Aircrew; Vision; Acuity; Contrast Sensitivity; Visual Fields; Glare Sensitivity; Colour Vision; Night Vision; Depth Perception; Motion Perception; Refractive Error; Air Command; Vision Standard; Pilot