DTA Report 405
NR 1686

Colour Vision Requirements for Aircrew

Ryan E Brookes
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ABSTRACT

Colour Vision Deficiency (CVD) is a condition that results in individuals being unable to distinguish differences between certain colours. The condition is most commonly inherited, affecting approximately 8% of men and a smaller proportion (0.5%) of women. Exclusion of applicants with CVD reduces the number of potential candidates available for selection as aircrew.

A continuum exists in the severity of CVD. At the most benign end of the continuum an individual may have near normal colour vision. At the opposite extreme, an individual may be monochromatic. The latter is extremely rare.

The compatibility of CVD with crewing aircraft is assessed by medical personnel using clinical diagnosis tests. These clinical tests were developed specifically to detect the presence, nature and severity of CVD. No clinical tests yet provide a measure of vocational performance in operating an aircraft.

Despite the lack of relevance to vocational performance, arbitrary pass marks have been assigned to clinical tests such that a failing candidate will either be subject to operational restrictions or excluded completely. The prescribed clinical tests and associated pass marks vary considerably between regulators. While an individual may be subject to no restrictions in one jurisdiction, they may be excluded in another.

In many civil and military populations, waivers have been given to CVD subjects who demonstrated competency in an operational environment. In some cases waivers were issued simply to achieve intake quotas. There is no record of such candidates suffering difficulty on operations as a result of their CVD. To the contrary there is much evidence to indicate that candidates with CVD, when aware of their condition, have been able to perform operational tasks to the required levels of competence.

This report presents and discusses available literature which indicates that aircrew with CVD are able to operate safely and effectively. The evidence raises questions about the suitability of current clinical test regimes as a means of restricting or disqualifying applicants. Consistent with the findings of NATO and the practice of some regulators, it is instead recommended that a practical or operational check, to identify practical handicaps as a result of CVD, is a more relevant and fair method by which to determine whether an applicant can safely crew an aircraft.

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EXECUTIVE SUMMARY

BACKGROUND

Colour Vision Deficiency (CVD) is a condition that results in individuals being unable to distinguish differences between certain colours. The condition is most commonly inherited, affecting approximately 8% of men and a smaller proportion (0.5%) of women. Exclusion of NZDF aircrew applicants with CVD reduces the number of potential candidates available for selection.

A continuum exists in the severity of CVD. At the most benign end of the continuum an individual may have near normal colour vision. At the opposite extreme, an individual may be monochromatic. The latter is extremely rare.

The compatibility of CVD with crewing aircraft is assessed by medical personnel using clinical CVD diagnosis tests, often in isolation from the operational community. These clinical tests were developed specifically to detect the presence, nature and severity of CVD. They are very good at this but no clinical tests yet provide a measure of vocational performance in operating an aircraft.

Despite the lack of relevance of current clinical testing to vocational performance, arbitrary pass marks have been assigned to clinical tests such that a failing candidate will either be subject to operational restrictions or excluded completely. The prescribed clinical tests and defined pass marks vary considerably between regulators. While an individual may be subject to no restrictions in one jurisdiction, they may be excluded in another.

Further complicating matters, in many civil and military populations, waivers have been given to those who have perhaps achieved the pass marks defined by other regulators or who have demonstrated competency in an operational environment. In some cases waivers have been issued simply to allow intake quotas to be achieved. There is no record of such candidates suffering difficulty in an operational environment as a result of their CVD despite not meeting the clinical test arbitrary pass mark. To the contrary there is much evidence to indicate that candidates with CVD, when aware of their condition, have been able to operate aircraft safely.

SPONSORS

Directorate of Evaluation and Airworthiness (Operational)

OC Aviation Medicine Unit

RESULTS

This report presents and discusses the available literature which indicates that aircrew with CVD are able to operate safely and effectively. The evidence raises questions about the suitability of current clinical test regimes as a means of restricting or disqualifying applicants. Consistent with the finding of NATO and the practice of some regulators, it is instead recommended that a practical or operational check, to identify practical handicaps as a result of CVD, is a more relevant and fair method by which to determine whether an applicant can safely crew an aircraft.

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1. INTRODUCTION

Colour Vision Deficiency (CVD) is a condition that results in individuals being unable to distinguish differences between certain colours. Congenital CVD affects approximately 8% of the male population. That equates to about 180,000 men in New Zealand. A smaller proportion of New Zealand women are also affected, numbering about 11,000. A further unknown proportion of the population suffers acquired CVD. The total population with CVD in New Zealand is sizeable, equating to about the entire population of Wellington.

Exclusion of applicants with CVD reduces the number of potential candidates available for selection as aircrew. This includes not only those applicants who are removed from the selection process during screening but also those who do not apply at all. This group may contain individuals who could otherwise provide talent to the NZDF.

A continuum exists in the severity of CVD. At the most benign end of the continuum an individual may have near normal colour vision. At the opposite extreme, an individual may be monochromatic and essentially see everything as shades of grey. The latter is extremely rare. The incorrect use of the term colour blindness obviously does not reflect the vast majority of individuals who can in fact differentiate colours, albeit to a different level of sensitivity than those with normal colour vision.

Regulation of CVD aircrew tends to polarise discussion amongst academics and regulators. At one extreme, some commentators espouse a view that individuals with CVD should be precluded from not only aircrew but transport in general. Other commentators and regulators have taken a more liberal stance which now sees a cohort of CVD individuals working in many professions including commercial and military aircrew. Within New Zealand, the compatibility of CVD with crewing aircraft is assessed by medical personnel using clinical CVD diagnosis tests, often in isolation from the operational community. These clinical tests were developed specifically to detect the presence of CVD. They are very good at this but no clinical tests yet provide a measure of performance with respect to operating an aircraft.

Despite the lack of relevance of current clinical testing to vocational performance, arbitrary pass marks have been assigned to clinical tests such that a failing candidate will either be subject to operational restrictions or excluded completely. The prescribed clinical tests and pass marks however vary considerably between regulators. While an individual may be subject to no restrictions in one jurisdiction, they may be excluded in another. This is true of both civil and military jurisdictions.

Further complicating matters, in many civil and military populations, waivers have been given to those who have perhaps achieved the pass marks defined by other regulators or who have demonstrated competency in an operational environment.

This report will present and discuss available literature concerning the appropriateness of current clinical test processes and pass criteria for CVD. The demands for colour perception associated with the use of colour in aircraft and ground systems will be discussed as will the operational experience of CVD aircrew. The recommendation of NATO and the practice of some regulators, to evaluate individuals with CVD by operationally relevant practical testing will be considered.

This report is a review of colour vision requirements in aviation with a first look at aircrew (pilots). It is recognised that there are many other roles in aviation where the issue of colour perception and testing is also in need of review. There is a need to look at the relevance of current testing methods for other aircrew such as flight engineers, air warfare officers and parachute jump instructors. There is also need to consider ground based trades such as aircraft technicians and engineers. These groups will be considered in the future.

2. COLOUR VISION

The literature provides a thorough review of current understanding of colour vision. NATO, ASIC and various aviation regulators and authorities have authored such reviews[1] [2] [3] [4]. To briefly summarise, the retina of the human eye contains photoreceptor nerve end cells which absorb light and channel nerve impulses to the brain for the perception of vision. There are two classes of photoreceptors – rods and cones. Rod cells function in low light conditions and are not sensitive to detail or colour. They provide night vision. Cone cells function in normal daylight providing perception of colour and detail.

There are three types of cone cell scattered randomly on the retina, each being sensitive to a different range of wavelengths (colours) of light. The L-cone is most sensitive to a spectrum of light centred at a wavelength of 570 nm (i.e. red). The M-cone is most sensitive to a spectrum of light centred at a wavelength of 542 nm (i.e. green) and the S-cone is most sensitive to a spectrum of light centred at a wavelength of 442 nm (i.e. blue). There is an overlap in colour sensitivity provided by each of the three types of cone, however the greatest sensitivity falls at the mentioned wavelengths. A deficiency with one type of cone may therefore be, to some extent, compensated by other cones. The sensitivity of the cones can be illustrated as shown by the United Kingdom Civil Aviation Authority in Figure 2.1[5]. The dotted line indicates the sensitivity of rod cells.

[1] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.
[2] Air and Space Interoperability Council, ADV PUB ASM 6012, ED 1 v2, Aircrew Colour Vision and Test Methods, 2015.
[3] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 1, United Kingdom Civil Aviation Authority, August 2006.
[4] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority.
[5] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 1, United Kingdom Civil Aviation Authority, August 2006.

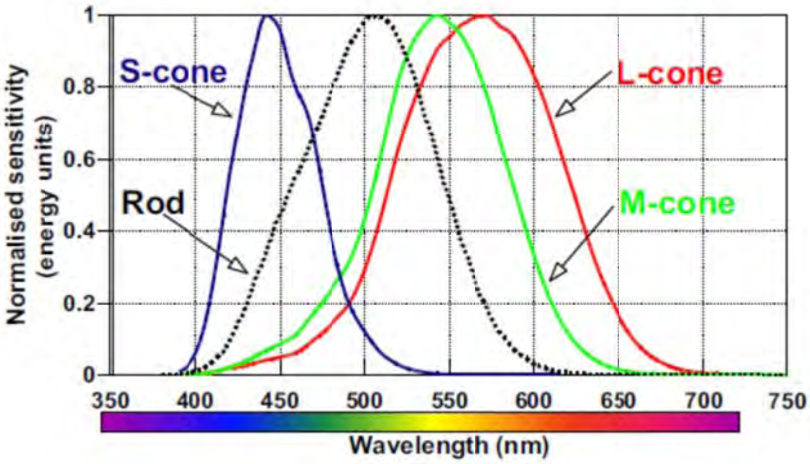

Figure 2.1 - Graphical representation of cone sensitivity across wave lengths

The perception of vision is complex and not fully understood. Just as there is overlap in the sensitivity of the cone cells, there is considerable integration of information within the nervous system and brain which provides our sense of vision and situational awareness. This complex network is also sensitive to changes other than just colour with size, brightness and movement being examples. Through mere sensing of colours we would not be able to drive at a wall at high speed and then brake to stop safely just a few inches from the wall. The same applies to recognition of objects and information. Colour perception alone does not provide adequate information to recognise an object or to react to its presence. Context is also required.

2.1 Colour vision deficiency

Congenital CVD is caused by anomalies with one or more of the three cone types and affects, on average, approximately 8% of the male population and 0.5% of the female population. There are three potential classifications[6]:

- Monochromatism affects those who have only one or no functioning cone receptors and so colour cannot be sensed. It is extremely rare, affecting no more than 0.003% of the population (about 135 people in New Zealand).
- Dichromatism affects those who have two functioning cone types. It affects approximately 2.1% of the male population and 0.03% of the female population (about 47,000 people in New Zealand).
- Anomalous trichromatism affects those who have all three cone types but one type has atypical sensitivity. This affects approximately 5.9% of the male population and approximately 0.4% of the female population (about 140,000 people in New Zealand).

A greater proportion of the male population is affected as congenital CVD is genetically transferred on the X chromosome. Symptoms only become apparent

[6] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 1, United Kingdom Civil Aviation Authority, August 2006.

when the full complement of X chromosomes is affected. Males have only a single X chromosome and so have a greater probability of developing symptoms than females.

Studies have found that congenital CVD may enhance the ability of an individual to detect camouflage. Aside from having an application in military and outdoors roles, this provides a potential evolutionary basis for the existence of CVD in a proportion of the male population[7 8].

2.2 Factors that affect colour vision

Colour perception in all individuals, including both those with normal colour vision and CVD, is affected by environmental factors, including[9 10]:

- Levels of ambient illumination
- Target brightness and saturation
- Proximity of adjacent colours as well as size, shape, texture and duration
- Visual fatigue and after images
- Health of the individual (age, drug use and disease)
- Filters such as coloured visors and sunglasses

Examples of colour perception variation, caused by the environment, can be found on the internet[11 12 13]. The United States Air Force noted the perception of colour by individuals with normal colour vision varied quite considerably when using helmet visor filters and eye protection[14]. Similar variances in the performance by individuals with normal colour vision have been reported in civil and military operations under coloured flight deck lighting and when wearing sun glasses[15]. Consequently, it is important to note that colour perception varies not just in those affected by CVD but also in those with normal colour perception, depending on the individual and the situation in which colours are observed. Aeronautical systems consequently need to provide redundant cues, beyond relying solely on colour.

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[7] Judd DB. Colorblindness and the detection of camouflage in Science. 1943; 97:544–6.
[8] Morgan, M.J., et al, Dichromats detect colour camouflaged objects that are not detected by trichromats, 1992.
[9] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 1, United Kingdom Civil Aviation Authority, August 2006.
[10] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.
[11] http://www.wired.com/2015/02/science-one-agrees-color-dress/
[12] http://www.ted.com/talks/beau_lotto_optical_illusions_show_how_we_see?language=en
[13] http://brainden.com/color-illusions.htm
[14] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.
[15] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.

3. USE OF COLOUR IN AVIATION

3.1 Aviation in the early 20th century

It has been reported that during the First World War the Royal Flying Corps introduced vision testing for applicants, including CVD testing, because of the importance of picking out the colour or markings of hostile aircraft, recognizing signal lights, and judging the nature of landing grounds[16].

In 1919 the Aeronautical Commission established the first international civil aviation colour vision standard, which stated[17]:

> *"If he is unable to distinguish pigmentary colors but is able to distinguish the coloured lights used in air navigation, his license may be rendered valid both for flight by night and for flight by day;*
>
> *If he is unable to distinguish either pigmentary colors or the colored lights used in air navigation, his license may only be rendered valid for flights by day, that is to say, for flights effected between sunrise and sunset."*

Louis Bauer was instrumental in the development of the first U.S. civilian aviation medical standards, requiring "normal" colour vision of all pilots. His medical textbook noted[18]:

> "*Normal colour vision is essential in a pilot because he has to distinguish landing lights on an airdrome at night; the navigation lights on other ships; an enemy plane from a friendly one; and finally the distinguishing of colour on the ground assists him in recognizing the terrain and in picking out landing places in an emergency."*

The requirement for the ability to perceive the colour and markings of aircraft in the era of World War One air combat is easy understood. Equally, the ability to accurately understand coloured flare and light signals, in a time when radio communications did not exist, is also reasonable.

Mention of the requirement for a colour vision standard to aid in selecting an emergency landing area is interesting given pilots were still allowed to fly by day if they did not meet the standard. Even today, glider pilots are not subject to CVD testing despite being more likely to need to select an unfamiliar landing site. The need for normal colour vision to allow the safe selection of landing site is therefore considered tenuous.

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[16] Watson, Dougal B., Lack of Uniformity in Assessing Color Vision Deficiency in Professional Pilots in Aviation Space Environmental Medicine, 2014, 85:148-59.
[17] Watson, Dougal B., Lack of Uniformity in Assessing Color Vision Deficiency in Professional Pilots in Aviation Space Environmental Medicine, 2014, 85:148-59.
[18] Watson, Dougal B., Lack of Uniformity in Assessing Color Vision Deficiency in Professional Pilots in Aviation Space Environmental Medicine, 2014, 85:148-59.

3.2 Colour vision demands in modern civil aviation

The demands of aircrew in the early 20th century, to identify enemy aircraft and to read coloured flares and signal lamps in the absence of radio communications, are not relevant to operations of today. Indeed, the New Zealand Civil Aviation Authority (CAA) medical manual states that colour signals are almost obsolete and testing for these is now irrelevant[19]. It is understood that the Airways Corporation of New Zealand is proposing the removal of signal lamps from New Zealand control towers in the near future. As such, historical requirements for a colour vision standard in an era of elaborately painted combat biplanes, coloured smoke and flare signals should not necessarily be used as the basis for such a standard today.

The colour vision demands of civilian aircrew in the modern era have been well examined on several occasions. The Administrative Appeals Tribunal of Australia conducted comprehensive reviews in the cases of Pape and Denison over the period 1987-1989[20] [21]. The latter case, formed a Commonwealth funded test case in 1989, and included over 30 days of testimony and evidence from specialists in the field. That work resulted in the removal of most restrictions on CVD pilots in Australia. Only two restrictions were retained:

- No Air Transport Pilot Licence (ATPL) privileges, precluding CVD aircrew from captaining multi crew operations.
- Limited to Australian airspace unless the regulatory authority of the second country is consulted.

Since that time, CVD aircrew have been permitted to fly all aircraft up to and including single pilot commercial airline operations (typical of regional airlines), night and day, under visual flight rules (VFR) and instrument flight rules (IFR) within Australian airspace. They were also permitted to co-pilot all operations regardless of aircraft size. ATPL privileges, permitting the captaining of multi crew operations, were then extended to those CVD pilots who passed a signal gun test. In relaxing the restrictions on CVD pilots, the Tribunal found that a CVD pilot can safely operate aircraft on commercial operations, day and night, VFR and IFR.

In 2015, a third Administrative Appeals Tribunal hearing extended ATPL privileges to a CVD pilot who had not achieved a pass on any administered colour vision testing[22]. The hearing provided an opportunity for the Tribunal to review the previous 26 years of commercial operations by CVD pilots in Australia. The Tribunal found:

[19] Medical Manual, Section 3.11.3.1, Ophthalmology, New Zealand Civil Aviation Authority, http://www.caa.govt.nz/medical/Medical_Manual/Med_Man_Part_3-11.pdf. Accessed 13 May 2015.
[20] Administrative Appeals Decision 3821, Pape and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.
[21] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.
[22] Administrative Appeals Decision 2014/1361, O'Brien and the Civil Aviation Safety Authority. Administrative Appeals Tribunal of Australia.

"*He was not likely to endanger the safety of air navigation in the role of Captain*" and "*his ability to operate aircraft safely with CVD is not in question*."[23]

Full records of all three hearings, including discussion of evidence, are available from the Administrative Appeals Tribunal website[24].

Independent of the Australian reviews, the United Kingdom CAA and contractors evaluated the colour vision demands placed upon civilian pilots in the modern era[25] [26] [27]. Consistent with the Australian reviews, very few circumstances were identified in which colour was relied upon to convey information. To quote the United Kingdom CAA report:[28]

"In almost all situations there were additional sources of information to aid the taking of a particular decision. Very few instances were found in which colour was the sole source of information and therefore likely to be safety critical in its own right".

Warning lights are a common example. The colour of the light is irrelevant. What is important is whether the light is on or off.

Acceptance that the use of colour is, by design, redundant or not critical in the conveyance of information is demonstrated by civilian regulatory authorities allowing individuals, with even the most severe forms of CVD, to operate aircraft by day. If CVD candidates could not read instrumentation, radios, maps and navigation aids, all of which are common to all operations of all size aircraft, from microlights up to heavy transports, then they would not be able to fly aircraft even by day.

3.3 NATO review of colour vision demands in modern military aviation

In 2001, the North Atlantic Treaty Organisation (NATO) completed a review of the colour vision requirements for military aviation. In that report NATO focused on demands associated with modern instrumentation stating[29]:

"*Generally speaking, colour vision aeronautical aptitude tests were created for reasons of safety and perception of the world outside the aircraft, whereas today, exterior indicators such as flares are almost redundant, and colour has entered the cockpit*".

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[23] Administrative Appeals Decision 2014/1361, O'Brien and the Civil Aviation Safety Authority. Administrative Appeals Tribunal of Australia.
[24] Decisions can be found using the search engine at http://www.aat.gov.au/AATDecisions.htm.
[25] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 1, United Kingdom Civil Aviation Authority, August 2006.
[26] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 2, United Kingdom Civil Aviation Authority, August 2006.
[27] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 3, United Kingdom Civil Aviation Authority, May 2009.
[28] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 2, United Kingdom Civil Aviation Authority, August 2006.
[29] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.

The NATO report did discuss the need to acquire target information visually. This discussion however focussed on the effect of filtered lenses and eye protection on all observers including those with normal colour vision. The particular devices under discussion were analogous to rendering the viewer dichromatic or monochromatic. That is to say, they have an extreme effect far in excess of the majority of anomalous trichromatism CVD cases. It was found that, for example, a yellow tinted visor could make detection of a yellow target more difficult. The feedback was however mixed with some observers reporting improved performance while others reported reduced performance. Ultimately the report recommended avoiding the use of filtered lenses and that nuclear blast filters required further consideration. The report also noted that aircraft displays are designed such that the use of colour is redundant and accommodate the use of such devices[30].

In considering instrument displays, NATO noted that international design standards, such as those of the International Organisation for Standardisation (ISO), accommodate CVD viewers and the use of filtered lenses[31]. It is understood that major aircraft manufacturers have incorporated these requirements into their proprietary design standards. This is not surprising given, as is mentioned throughout this report, a sizeable proportion of aircrew (both civil and military) are known to be CVD. Their entry into the aircrew population has been facilitated by liberal screening processes in many countries along with legislation which allows CVD pilots to operate aircraft in spite of CVD. In some cases this is only by day while in other jurisdictions it is under all conditions.

Based on the NATO review it would be reasonable to conclude that CVD will not affect the ability of an applicant to operate an aircraft. Definitive information could not be found on whether CVD could affect some particular military roles such as targeting ground targets during combat missions or identifying ground objects during searches. That said, such roles may not be relevant to all aircrew. Further, as will be discussed subsequently, given that CVD pilots have been able to pilot rescue helicopters in other countries such as Australia, Canada and the United States for many years and operate military aircraft in some jurisdictions, it would appear that search and targeting type missions may also be accomplished by CVD aircrew.

To quote Dr John Firth, neurosurgeon, neuroscience advisor and medical panel member for NATO[32]:

> "*In the selection of aircrew, airborne or remote, the potential future aces, upon whose cunning and intelligence the defence of realms will depend, may be colour defective. There is no established relationship between colour and military, let alone commercial or civil, competence. The future's essential hero may not be colour normal. Do we, dare we exclude the otherwise best candidates on colour competence alone?*"

Dr Firth further states the legacy requirement for colour perception is "*presumed*"[33].

[30] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.
[31] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.
[32] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001

3.4 Expert opinion of Professor Boris Crassini

Professor Boris Crassini is a retired professor of psychology of Deakin University, Australia. His areas of academic research were human visual perception and infant development of perception. He has appeared as an expert witness in several cases concerning colour vision and its relevance in the workplace. This has included the aviation industry. Professor Crassini states[34]:

> *"Defective colour vision is a real phenomenon as reflected in, for example, the impaired ability of people with defective colour vision to name and discriminate emitted or reflected light of particular wavelengths. If asked to perform a task the performance of which depends critically on the ability to name and discriminate emitted or reflected light of particular wavelengths, people with defective colour vision will exhibit impaired performance compared with the performance of people with normal colour vision.*
>
> *I am unaware of any evidence that shows that the safe performance of piloting an aircraft depends critically on the ability to name and discriminate emitted or reflected light of particular wavelengths. Therefore, it follows logically that people with defective colour vision are able to pilot aircraft safely."*

3.5 Expert opinion of Associate Professor Geoffrey Stuart

Associate Professor Geoffrey Stuart of the Accident Research Centre of Monash University works in the area of visual perception and, referring to CVD piloting experience in Australia, states[35]:

> *"The demonstrated ability of CVD pilots to use aircraft systems is highly relevant, and has convinced the Administrative Appeals Tribunal that pilots of demonstrable ability do not represent a risk to aviation safety when appropriate conditions are imposed."*

3.6 Expert opinion of Professor Barry Cole

A review of the literature found no definitive material to indicate that normal colour vision is required for aircrew in modern aviation. Professor Barry Cole, a retired optometrist from Melbourne University appears to have been the most prolific author of papers advocating the exclusion of individuals with CVD from aviation. Indeed, Professor Cole authored papers advocating the exclusion of CVD individuals from all forms of transport, citing the risk of confusing colour signals or missing signals altogether. The work of Professor Cole is however generally focused on clinical test

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[33] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001

[34] Crassini, B., Report to the Administrative Appeals Tribunal in the case of O'Brien and the Civil Aviation Safety Authority, 2 August 2013.

[35] Stuart, G., Colour Vision Deficiency and Aviation Safety; A Submission to the Civil Aviation Safety Authority, June 2015.

methods and simulation by clinical test methods and is discussed later in this report. His work was examined by the Administrative Appeals Tribunal of Australia when considering the Commonwealth funded test case of 1989. Ultimately that review concluded a relaxation of conditions on CVD pilots, as already discussed.

4. COLOUR IN SPECIFIC AERONAUTICAL SYSTEMS

Commentators have identified in the literature a number of systems which utilise colour in conveying information. Some have indicated that these may be reason to restrict or disqualify CVD aircrew applicants. These include:

- Precision approach path indicator (PAPI).
- Hazard marker beacons.
- Signal gun.
- Aircraft navigation lights.
- Airfield lighting.
- Flight deck displays.
- Maps.

All of these subject areas were discussed at length during the previously mentioned Australian Administrative Appeals Tribunal reviews and studies in the United Kingdom and United States[36] [37] [38] [39]. The reader should refer to those studies for the full discussion and expert testimony for each.

In considering each of the listed subject areas, it is first necessary to consider the processes associated with flying an aircraft. When qualified aircrew undertake a flight, considerable preparation occurs. The crew is first and foremost licenced, type rated and current on the aircraft type for the flight, whether that be by day, night, VFR or IFR. Prior to being issued with various levels of licences and ratings, pilots undertake a significant amount of training under the supervision of experienced flight instructors. Their performance is later assessed by qualified flight examiners against set operational competencies. These standards are then reassessed at regular intervals. The pilot consequently has a good level of familiarity with the aircraft and its systems and has demonstrated competence in their use.

Prior to the flight, the pilot prepares by gathering weather information, planning the flight, marking maps, listing radio frequencies and telephone numbers, reviewing navigation aids, notices to airmen (NOTAMS) and airport plates, inspecting the aircraft and filing the flight plan.

Consequently, by the time of the flight, the pilot is familiar with how and where information will be conveyed during the course of the flight. During clinical testing,

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[36] Administrative Appeals Decision 3821, Pape and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.
[37] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.
[38] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 2, United Kingdom Civil Aviation Authority, August 2006.
[39] Report DOT/FAA/AM-14/6, Usability of Light Emitting Diodes in Precision Approach Path Indicator Systems by Individuals with Marginal Color Vision, Federal Aviation Administration, May 2014.

this background training and familiarity is not available to the applicant; however it is against this background that the ability of a pilot to fly an aircraft and gather information should be assessed. The systems and equipment where colour may be encountered will now be discussed.

4.1 Precision Approach Path Indicator (PAPI)

The Visual Approach Slope Indicator (VASI) was developed in the 1950s as an aid to pilots in obtaining the correct approach slope when landing. The PAPI is an evolution of the VASI, introduced in the early 1970s.

The PAPI displays four lights to an aircraft on approach. Each is angled such that aircrew will see a different combination of lights depending on the slope of their approach. If flying the nominal approach path, the crew will see two red and two white lights as depicted in Figure 4.1. If slightly higher they will see three white and one red. If still higher they will see four white. If slightly low they will see three red and one white. If very low they will see four red lights[40].

Figure 4.1 - PAPI lights to the left of the runway lights. Two red and two white lights as pictured indicate the nominal approach path. Notice the red lights are of lower intensity

4.1.1 CHROMATIC CONTENT OF PAPI LIGHTS

The chromatic content of incandescent lighting used in aviation, including the PAPI, is defined by SAE International standard AS 25050A. The chromatic content of LED lighting is defined by Federal Aviation Authority (FAA) Engineering Brief 67D[41].

When examining the effect of changing from incandescent to LED lighting in the PAPI, the FAA developed a PAPI simulator for use in clinical trials. The simulator was designed to be realistic of a fielded PAPI, utilising actual PAPI lens material. Candidates with normal colour vision as well as varying forms and severity of CVD were asked to identify signals on the simulator for both incandescent and LED lighting. In that study, there was no difference in performance between candidates with normal colour vision and those with CVD when using incandescent lights. The

[40] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 3, United Kingdom Civil Aviation Authority, May 2009.
[41] Advisory Circular AC 150/5345-28G, Precision Approach Path Indicator Systems, Federal Aviation Administration, 29 Sep 2011.

move to LED technology actually saw CVD candidates outperform candidates with normal colour vision and achieve perfect scores in the PAPI test[42].

The ability of CVD subjects to read the PAPI is not surprising. The light colours used in the PAPI are, by design, selected such that they will not be confused with one another even by an individual with CVD. The colours may be plotted on the CIE 1931 colour space. Colour confusion lines for protan (reduced red sensitivity), deutan (reduced green sensitivity) and tritan (reduced blue sensitivity) variants of CVD may then be also plotted as has been done in Figures 4.2, 4.2 and 4.4[43]. Colour confusion lines are lines along which two colours may be confused by a protan, deutan or tritan CVD observer. If two colours do not sit on the same radial line they are less likely to be confused. As can be seen, for protan, deutan and tritan CVD subjects there is little chance of confusion between white and red aviation lights, whether incandescent or LED.

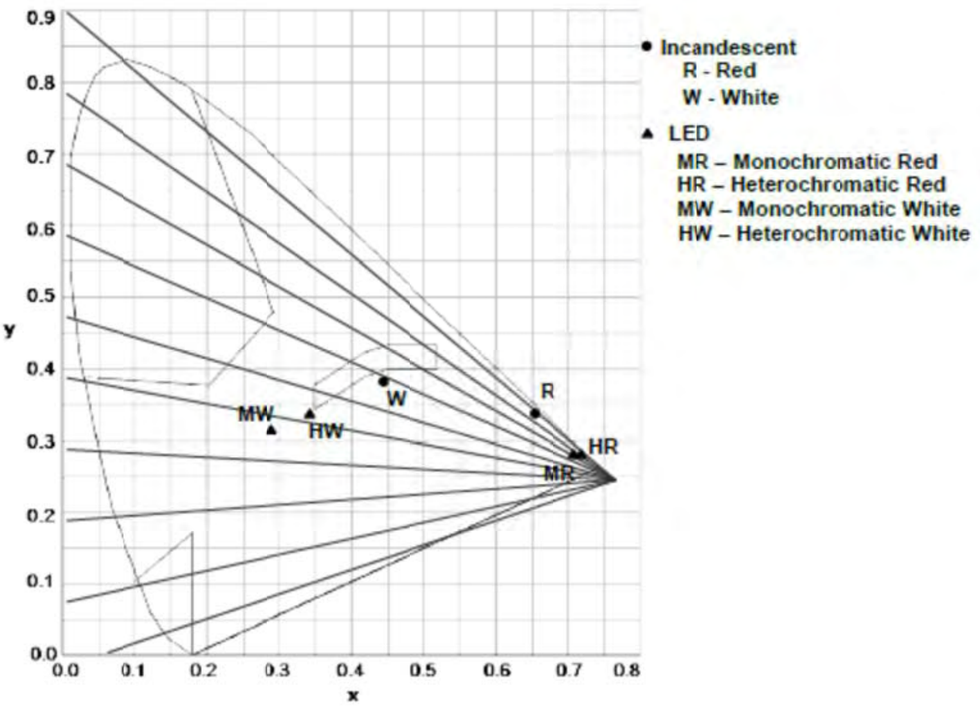

Figure 4.2 - CIE 1931 colour space and colour confusion lines for protan subjects (reduced red sensitivity) showing PAPI red and white incandescent and LED lights do not lie on common colour confusion lines[44]

[42] Report DOT/FAA/AM-14/6, Usability of Light Emitting Diodes in Precision Approach Path Indicator Systems by Individuals with Marginal Color Vision, Federal Aviation Administration, May 2014.
[43] Report DOT/FAA/AM-14/6, Usability of Light Emitting Diodes in Precision Approach Path Indicator Systems by Individuals with Marginal Color Vision, Federal Aviation Administration, May 2014.
[44] Report DOT/FAA/AM-14/6, Usability of Light Emitting Diodes in Precision Approach Path Indicator Systems by Individuals with Marginal Color Vision, Federal Aviation Administration, May 2014.

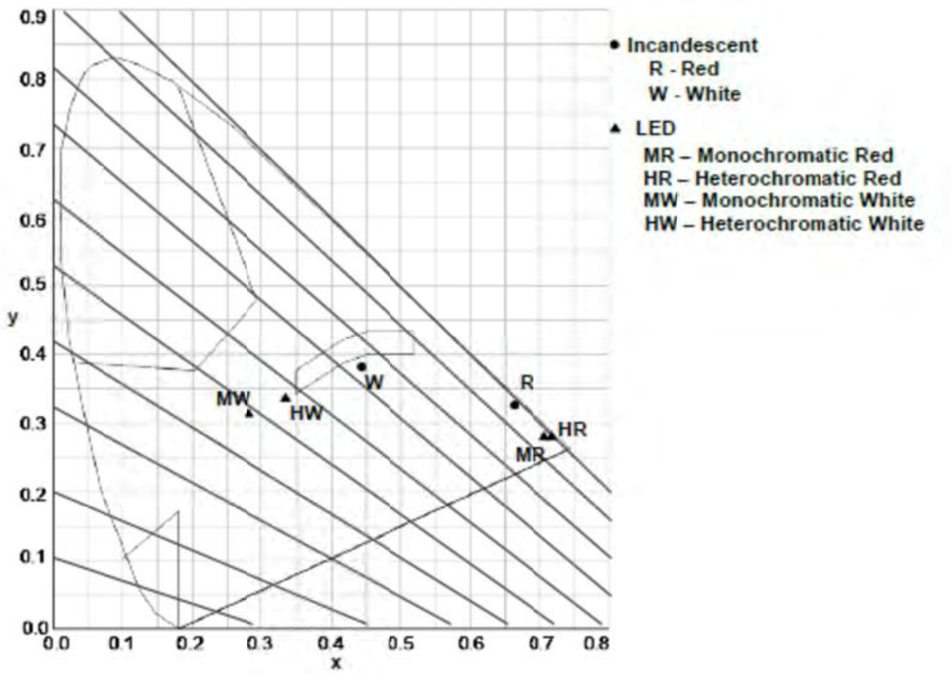

Figure 4.3 - CIE 1931 colour space and colour confusion lines for deutan subjects (reduced green sensitivity) showing PAPI red and white incandescent and LED lights do not lie on common colour confusion lines[45]

[45] Report DOT/FAA/AM-14/6, Usability of Light Emitting Diodes in Precision Approach Path Indicator Systems by Individuals with Marginal Color Vision, Federal Aviation Administration, May 2014.

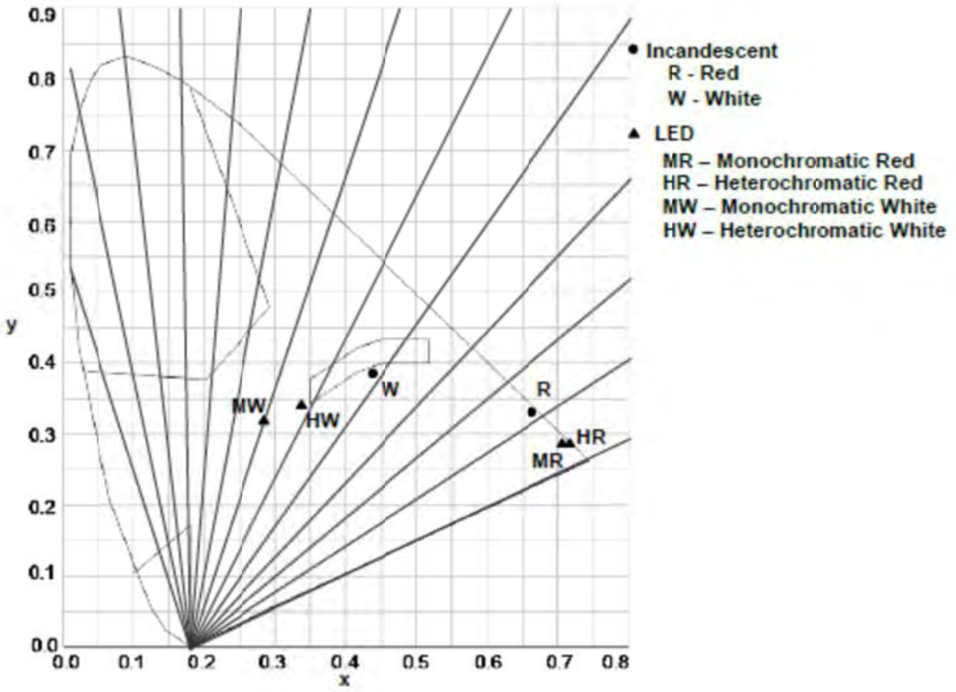

Figure 4.4 - CIE 1931 colour space and colour confusion lines for tritan subjects (reduced blue sensitivity) showing PAPI red and white incandescent and LED lights do not lie on common colour confusion lines[46]

To quote Professor Geoff Stuart of the Monash University Accident Research Centre[47]:

> *"A recent study by the U.S. Federal Aviation Administration tested individuals with various forms of CVD on a more realistic PAPI simulator. Importantly, the colours of the lights corresponded to those of real systems. Dichromats (lacking red-green colour vision) performed better than normal trichromats. This was not surprising as the red and white lights in the PAPI would not look the same to dichromats, who would see the red light as yellow/brown."*

4.1.2 INTENSITY DIFFERENCES IN PAPI LIGHTS

Approach path information is not just conveyed by colour alone. Engineering specifications for the PAPI require there to be a difference in intensity between the red and white signal lights with the white lights being 2 – 6.5 times as intense as red lights[48] [49]. The PAPI thus conveys approach path information using both colour and

[46] Report DOT/FAA/AM-14/6, Usability of Light Emitting Diodes in Precision Approach Path Indicator Systems by Individuals with Marginal Color Vision, Federal Aviation Administration, May 2014.
[47] Stuart, G., Colour Vision Deficiency and Aviation Safety; A Submission to the Civil Aviation Safety Authority, June 2015.
[48] Advisor Circular AC 150– 5345-28 Precision Approach Path Indicator (PAPI) Systems, Federal Aviation Administration, 29 Sep 2011
[49] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.

intensity with the observer, whether CVD or colour normal, able to perceive the different PAPI signals as darker red or brighter white. In the case of the FAA PAPI simulator previously discussed, the intensity difference was deliberately reduced to just 20% - well below that of operational PAPI. Even with this conservative measure, CVD observers still read the PAPI signals as accurately as colour normal observers[50].

To quote the Administrative Appeals Tribunal[51]:

> *"We are satisfied that, because of the size and brightness of the VASIS lights, changes from one colour to another will be perceived by pilots with defective colour vision as changes both in colour and in intensity. Deutans will almost certainly perceive the red light as such and any other colour as something different. Protans will see the red light as having significantly decreased intensity compared with the other colours. So there is no significant risk of protan or deutan pilots maintaining the incorrect height during their approach to an aerodrome because of inability to make proper use of the VASIS."*

This conclusion is supported by empirical evidence of CVD pilots when using the real PAPI system in an operational environment over many years of operations.[52]

4.1.3 REDUNDANCY TO PAPI

Research by the Australian Defence Science and Technology Organisation (DSTO) determined that the colour signals provided by PAPI lights could be altered by the presence of moisture or dust contamination on the PAPI light lens. Under such circumstances, the red and white light beams are refracted and mixed such that the combined beam may appear pinkish-white and be unreadable to all observers. This research has also been duplicated in the United States and Canada and may result in observers receiving incorrect information from a PAPI system if relying on colour interpretation alone. It is for this reason that warnings are presented to aircrew through the Air Information Publication (AIP), indicating that the PAPI system should be used only as an aid to an approach and may provide erroneous indications[53] [54] [55]. It is also for this reason that the PAPI is not used in isolation when making an approach.

In addition to the colour and brightness cues provided by the PAPI, the geometric appearance of the runway and approach lights themselves is used to determine approach path[56]. Some smaller airfields do not feature PAPI lights at all but instead

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[50] Report DOT/FAA/AM-14/6, Usability of Light Emitting Diodes in Precision Approach Path Indicator Systems by Individuals with Marginal Color Vision, Federal Aviation Administration, May 2014.
[51] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.
[52] Administrative Appeals Decision 2014/1361, O'Brien and the Civil Aviation Safety Authority. Administrative Appeals Tribunal of Australia.
[53] Systems Report 25, Hazards of Colour Coding in Visual Approach Slope Indicators, Defence Science and Technology Agency, Department of Defence, Australia, 1981.
[54] Air Information Publication Volume 4, Airways Corporation of New Zealand, 2015.
[55] Report DOT/FAA/CT-82/153, Evaluation of Precision Approach Path Indicator (PAPI). Federal Aviation Administration, April 1983.
[56] Report FAA-AM-79-25, Runway Shape as a Cue for Judgement of Approach Angle, Federal Aviation Administration, November 1979.

rely on pilots interpreting their approach path by this geometric appearance of the runway lights. Discussions with aircrew have confirmed that this may also occur at major airfields on occasion during periods of PAPI maintenance. In such circumstances, colour is not used at all in defining the approach slope.

For commercial operators, strict limitations are placed upon the use of visual approach aids such as PAPI. As the PAPI is vulnerable to error, aircrew are required, by airline standard operating procedures, to utilise approach instrumentation and automation. Consequently, the conveyance of approach path information by PAPI light colour is just one of four ways by which the crew of a commercial aircraft will ascertain their approach slope - PAPI light colour, PAPI light intensity, runway light geometry and aircraft instrumentation. In the case of airfields without PAPI, colour is not used at all.

For larger aircraft such as the Airbus A320, aircrew are in fact cautioned against using PAPI indications below 200 ft above ground level as the indications are incorrect for their size of aircraft. On such aircraft, because of their size, the PAPI will provide inadequate clearance of the undercarriage at the runway threshold[57]. In the case of a visual approach, the aircrew will rely on runway geometry cues. In the case of an instrument approach, the aircrew will transition directly from instruments to looking at the runway geometry late in the approach.

4.1.4 USE OF PAPI IN CONDITIONS OF POOR VISIBILITY

Although not documented or referenced, it is occasionally raised by commentators that PAPI light intensity cues (differences between the intensity of red and white PAPI lights) may be lost in conditions of low visibility thereby increasing demand on colour naming. However, in such conditions aircrew will not rely on PAPI. In the case of visual approaches, conditions of poor visibility will preclude operations in total due to legal meteorological minima applying. Alternatively, instrument approaches will be flown, in which case the PAPI is superfluous and may not be observed at all by the crew of an aircraft flying an instrument approach through low cloud, mist or fog.

It is understood that in Australia and New Zealand all airports which have PAPI installed also have an associated runway instrument approach procedure. This may be in the form of a ground based navigational aid such as an instrument landing system (ILS) or a global navigation satellite system (RNAV/GNSS) approach procedure. Instrument approach plates contain a table of distance versus altitude, which provides another means of verifying the aircraft is on the correct approach path. Furthermore, aircrew use simple rules of thumb to further cross-check standard three degree glide paths which equates to 320 ft/nm. For example, 1 nm final = 320 ft, 2nm final = 640 ft, 3nm final = 960 ft.

4.2 Hazard marker beacons

Some hazards such as tall buildings or high terrain may be marked by lights or beacons. This is not universal and the absence of a beacon does not mean the absence of high ground or buildings. Moreover, the presence of a beacon does not necessarily mean there is a building or high ground present as the beacon could, for example, be on another aircraft.

[57] Airbus A320 Flight Manual, 2015.

The appearance of beacons is not consistent. In some cases a steady red light may be used however in other cases alternative light colours may be used. In some cases, such as the high point at an aerodrome, a flashing or rotating white beacon may be used.

In considering the pre-flight planning that aircrew undertake prior to a flight, the presence of high features which may be hazardous to an aircraft will be noted from notices to airmen (NOTAM), plates and maps, whether that feature is marked by a beacon or not and whether that feature is permanent or temporary. Assuming that every hazardous feature will be marked by a beacon and relying on every beacon to be serviceable and visible is far from satisfactory airmanship.

In the case of flight in instrument meteorological conditions (IMC), including instrument approaches, reliance on being able to visually detect a hazard marker beacon is irrelevant. At night and in IMC, aircrew are required to fly the aircraft above the pre-calculated lowest safe altitude (LSALT) or minimum sector altitude (MSA) and may only descend below these altitudes in accordance with strict procedures.

The various reviews that have been mentioned did not consider hazard marker beacons to provide adequate basis for restricting or disqualifying CVD aircrew applicants.

4.2.1 DETECTION OF RED BEACONS

Professor Barry Cole, a retired optometrist from Melbourne University, has written that individuals with protan (reduced red sensitivity) type CVD have a reduced ability to detect red beacons[58]. From this conclusion he argues that CVD applicants should be subject to disqualification from occupations in transport industries as they may have difficulty in distinguishing traffic signals, hazard lights and brake lights and hence be more likely to suffer accidents.

Verriest et al however surveyed 2,058 male drivers who caused road accidents and found the proportion of CVD drivers involved in accidents was the same as the occurrence of CVD in the broader population. Further, a sample of 1,926 'rear end' type accidents caused by male drivers was investigated. 41 accidents or 2.1% were caused by male protan CVD subjects[59]. The prevalence of protan CVD in the male population is approximately 2.2-2.7% [60] [61] and so it would appear that even protan CVD has had no bearing on the detection of traffic or brake lights leading to rear end accidents. Further supporting this conclusion, there is no legislation relating to CVD drivers and there is no known insurance loading related to CVD. By comparison, for example, drivers under the age of 25 account for a disproportionately large

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[58] Cole, B. L. and Vingrys, A. J. Do protanomals have difficulty seeing red light? Proceedings 20th Session of the Commission Internationale d'Eclairage, 1E 04/1, The Netherlands. CIE, Paris, France, 1983.
[59] Cole, B.L. and Maddocks, J.D., Defective Colour Vision is a Risk Factor in Driving in Colour Vision Deficiencies. Proceedings of the 13th Symposium pp 472-480, 1997.
[60] Medical Manual, Section 3.11.3.1, Ophthalmology, New Zealand Civil Aviation Authority, http://www.caa.govt.nz/medical/Medical_Manual/Med_Man_Part_3-11.pdf. Accessed 13 May 2015.
[61] Air and Space Interoperability Council, ADV PUB ASM 6012, ED 1 v2, Aircrew Colour Vision and Test Methods, 2015.

percentage of road accidents and pay higher insurance levies as a result. There is also considerable legislation around licencing of younger drivers[62]. There is no similar evidence to suggest that CVD subjects have a reduced ability to react to red signals or brake lights in an operational environment.

The view that a protan CVD subject may have a reduced ability to detect red signals is based on Allard's law. It is however a theoretical model which does not necessary hold true in practice. To quote the Australian Administrative Appeals Tribunal[63]:

> *"An interesting demonstration of the ability of a protanope with above average visual acuity to recognize very small red dots at a distance when a person without such good visual acuity did not see those dots at all was given by Captain R. Cronin. A number of photographs taken from an aircraft at night by Dr Pape were projected onto a screen. Captain Cronin stood about 10 ft from the screen and members of the Tribunal were nearer to the screen than he was. He identified the red dots, which in the scene photographed by Dr Pape were red lights, when they were not visible at all to some of us. Captain Cronin gave evidence that he was a protanope and that he had distant visual acuity of 6/5 without correcting lenses. It was apparent to us that, if the Allard's law formula were correct, the furthest distance at which a protanope with 6/6 distant visual acuity could see a red light would be approximately the same as the furthest distance at which a person with normal colour vision but a distant visual acuity of 6/12 could see it."*

To paraphrase, the subject who was a protanope (dichromatic and devoid of long wavelength cones) should, according to Allard's law, be insensitive to red lights and have difficulty detecting them. The subject did however identify the red lights at a distance greater than that at which individuals with normal colour vision could detect the lights. Several other examples were presented to the Tribunal. To quote the Tribunal in the case of O'Brien, a severe protanope:

> "*His ability to operate aircraft safely with CVD is not in question*."[64]

Consequently, the practical evidence presented to the Tribunal as well as land transport accident experience indicates that CVD appears to have no significant bearing on the ability of an individual to react to red lights.

4.3 Signal gun

A signal gun is a hand held device used to direct a light signal to an aircraft in order to convey a message. While common before the proliferation of aircraft radios, use of signal guns is now extremely rare with practically all modern aircraft featuring radio communications. In the case of aircraft utilised in air transport operations,

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[62] Young Drivers, Ministry of Transport, 2014.
[63] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.
[64] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.

multiple radios are required by legislation. There are also multiple redundancies, including voice modulated navigational aids, mobile phones and often satellite phones. The likelihood of the crew of an aircraft needing to receive a signal gun message is therefore remote. The CAA Medical Manual states:

> *"Use of visual signals for clearances (red, green and white) by Air Traffic Controllers has become almost obsolete. Thus functional testing with those lights has become irrelevant*[65]*.*

It is understood that the Airways Corporation is looking to remove signal guns from control towers in New Zealand.

Moreover, the practicality of a large aircraft responding to a signal gun should also be considered remote. The ability of a controller to convey a meaningful message to a commercial aircraft by signal lamp whether on the ground or in the air is limited. While it is possible that a signal gun could provide means to message a light aircraft which is able to turn on a taxiway or hold near to the control tower when airborne, alternative procedures, including phone numbers, are provided for such aircraft in aerodrome landing plates. All aircrew, during the course of their training, learn radio failure procedures for dealing with such emergencies.

This risk appears to have been accepted by regulators as CVD aircrew are already permitted to operate by day in controlled airspace in radio equipped aircraft. There is no record of any issues with such operations and there is no reason why such operations at night should be any more difficult. To the contrary, interpretation of a signal gun is likely to be easier at night when the light is more obvious against a dark background.

4.4 Aircraft navigation lights

Aircraft of all sizes feature navigation lights. An adaptation of maritime technology, aircraft are fitted with three lights – red on the left extremity, green on the right extremity and white on the tail. The intent of these lights was to enable the presence and direction of travel of ships and aircraft to be determined. This was previously mentioned as a basis for the 1919 requirement for CVD testing.

Since 1919, aircraft lighting has evolved significantly. Early navigation lights were basic but now we see rotating beacons, strobe lights, high intensity landing and taxi lights, flashing landing lights and tail illumination, all of which are visible from much greater distances than navigation lights. Relative motion of another aircraft is very quickly and easily determined at great distances by the relative motion of the lights just as the relative motion of an aircraft during the day provides a quick indication of a collision risk.

Moreover, collision avoidance technology is ubiquitous and is increasingly common place even in general aviation, where lower production costs have aided its adoption. The introduction of ADS-B further enhances aircraft tracking and collision avoidance practices. Reliance on the recognition of the colour of individual navigation lights is

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[65] Medical Manual, Section 3.11.3.1, Ophthalmology, New Zealand Civil Aviation Authority. http://www.caa.govt.nz/medical/Medical_Manual/Med_Man_Part_3-11.pdf. Accessed 13 May 2015.

now largely irrelevant and indeed impractical for the prevention of collisions between modern high speed aircraft operating in poor weather conditions.

This discussion doesn't consider the scenario of night formation flying and no literature could be found concerning this unique military task. None the less, as will be discussed later in this report, a significant number of CVD pilots are known to have served with the US Army. Some have reached high rank and flown many thousands of flight hours over several decades. Given there are no reported occurrences within this population, it would suggest that CVD pilots have been able to perform military aviation duties, which invariably include night operations, without issue.

4.5 Airfield lighting

The previously mentioned reviews by the Administrative Appeals Tribunal of Australia and the UK CAA considered external lighting when determining whether CVD would impact pilot performance. In the case of the Australian reviews it was demonstrated that the same information was available whether presented with or without colour. To quote the Administrative Appeals Tribunal[66]:

> *"The research into the value of colour at airports was conducted by Dr R. K. McKelvey. Evidence of the results of that research was given to the Tribunal in the proceedings in Re Pape. The persons used by Dr McKelvey for his experiments were experienced pilots. He projected onto a screen a series of photographs of airports as seen by pilots approaching them. To one group of subjects he showed the photographs in colour and to the other in black and white. He found that the group to whom they were shown in black and white had no difficulty in quickly identifying what they saw. He concluded that the perception of colour was not vital to safe use of airport lighting as a source of information to pilots."*

> *"So far as taxiway lights are concerned, if they are blue they are seen by protans and deutans without any difficulty or error. If they are green they are in a single line which starts in the middle of the runway, turns off it and then continues; as a runway is always marked by two lines of white lights, one on each side of the runway, the fact that there is only a single line is by itself an adequate cue that the lights mark a taxiway and not a runway. Red lights indicating holding points are at right angles to the taxiway; because of that, perception of them as lights is sufficient to indicate to a pilot that they mark a holding point. In the case of deuteranopes there is little chance that the lights will not be perceived as red, particularly when the aircraft is near to them. Furthermore, when a pilot comes upon them, his aircraft is not travelling fast and he is under the direction of an air traffic controller who can observe where his aircraft is and give him appropriate instructions. We have come to the conclusion that any diminution of the intensity of red light perceived by a protanope will not prevent him from seeing the lights in ample time to stop his aircraft at them and that any possible inability of a pilot who is a protan or a*

66 Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.

deutan to perceive holding point lights as red will not prevent a pilot being aware of their significance or prevent him from operating his aircraft safely on an aerodrome. Similarly we are satisfied that a pilot with defective colour vision will recognise the line of red or green lights at the end of a runway as what it is because of its direction relative to the runway lights."

To summarise, the geometric appearance of ground light arrangements combined with the saturation of colour they provide mean that CVD aircrew will have little issue in interpreting airfield lighting.

4.6 Flight deck displays

Some literature raise flight deck instrumentation as a potential source of difficulty for CVD pilots despite also acknowledging that the use of colour in such displays is, by design, redundant and designed for use by CVD aircrew[67] [68]. As already discussed, redundancy in the form of luminance cues and colour separation is incorporated by design standards not only to accommodate CVD but also the use of filtered lenses and sunglasses.

4.6.1 USE OF COLOUR AND INTENSITY IN FLIGHT DECK DISPLAYS

An example of a modern electronic flight instrumentation system (EFIS) style display is depicted in Figures 4.5 and 4.6, first in full colour and then with all colours reduced in saturation by 50%. The same information may be obtained from either image. Colour use is such that CVD observers may also read the displays either because of the colour combinations used or because of luminance differences (light against dark).

Figure 4.5 - EFIS display of attitude indicator and horizontal situation indicator

[67] Medical Manual, Section 3.11.3.1, Ophthalmology, Civil Aviation Authority. http://www.caa.govt.nz/medical/Medical_Manual/Med_Man_Part_3-11.pdf. Accessed 13 May 2015.
[68] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001

Figure 4.6 - Same EFIS display with a 50% reduction in colour

4.6.2 ADMINISTRATIVE APPEALS TRIBUNAL REVIEW OF FLIGHT DECK DISPLAYS

The topic of flight deck instrumentation was examined at length by the Australian Administrative Appeals Tribunal and the United Kingdom CAA. The extent of the evidence on the topic precludes it being repeated here. Instead the reader is referred to the Administrative Appeals Tribunal findings in the case of Denison and the UK CAA work. In all cases it was found that information displayed on instruments including EFIS displays typical of modern aircraft is legible to CVD pilots[69]. It was also found that there would be no disadvantage of note in an operational setting for CVD pilots in the speed or accuracy of their response[70].

The discussion of weather radar by the Administrative Appeals Tribunal in the case of Denison summarises the topic[71]:

> *"In coming to a conclusion on this aspect of the issue of colour inside the cockpit, we again note that, at whatever time the pilot looks at the weather radar screen after take-off, it is not the first occasion on which he has looked at it in the course of that flight. Before commencing the flight he has obtained meteorological information and has prepared his flight plan accordingly. The weather situation which he sees displayed on the weather radar develops as the flight progresses. While unexpected meteorological conditions may be encountered, the screen will change gradually as the changes in the weather develop. Some of the colours used are colours that a protanope or a deuteranope has little trouble in identifying. Those which he does have trouble with will usually be displayed in sufficient quantity and with sufficient brightness, that, with the screen so near to his eyes, his retina will be so suffused with them that the mechanism within the retina to which we have referred above, whatever it is, will respond to the stimuli sufficiently for him to perceive the colour differences. That process is*

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[69] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 2, United Kingdom Civil Aviation Authority, August 2006.

[70] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.

[71] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.

doubtless aided by the different luminance of the various colours, to which Mr Chatfield referred. Additionally the boundaries of different colours representing on the radar screen different precipitation rates are clearly defined; those shapes will be available to the pilot with defective colour vision. Consequently, we have come to the conclusion that a pilot who is a protanope or a deuteranope is able to obtain readily from the weather radar screen the information about the weather which he needs in order to fly his aircraft safely. It accords with evidence given at the hearing by pilots with defective colour vision, including the applicant."

4.6.3 USE OF FLIGHT DECK DISPLAYS BY CVD AIRCREW

Academic researchers, Mahon and Jocobs attempted to evaluate the ability of untrained CVD individuals to utilise the EFIS displays of the Boeing 747-400 aircraft. The study was flawed however in that it simply required respondents to name the displayed colours. This test of colour naming did not measure the ability of individuals to actually utilise displayed information in an operational activity.[72]

CVD aircrew routinely have flown with EFIS displays across a range of aircraft types. Indeed, such displays are now common place in many modern light aircraft that are entering service in New Zealand and other countries. Such displays may be expected to be harder to read during daylight conditions when stray light hinders visibility of the screen, however there is no empirical evidence, anecdotal or otherwise, to suggest that CVD aircrew have difficulty in this environment. Civilian regulatory authorities continue to allow CVD aircrew to operate such aircraft.

4.6.4 MONOCHROMATIC NIGHT VISION EQUIPMENT

Increasingly, use is being made of night vision equipment by flight crew, particularly in the high demand low level environment of search and rescue helicopter operations. Such equipment is also routinely used in large aircraft operations and military ground attack aircraft operations. Night vision equipment and associated filters renders all screens varying intensities of monochromatic green, removing any colour coding that may have been present on the aircraft instrumentation, as displayed in Figures 4.7 and 4.8.

[72] Mahon, L. E. and Jacobs, R. J. (1991) Electronic Flight Information System displays and colour defective observers. *Clinical and Experimental Optometry*, 74(6), 96-203.

Figure 4.7 - BELL 412 Standard Instrument Panel – Full Colour

Figure 4.8 - BELL 412 Standard Instrument Panel – Equipped for Night Vision Goggles (NVG). All flight, engine and performance instruments are monochromatic (Green)

While this example shows analogue instrumentation, the appearance is similar for EFIS style instrumentation. Given aircrew with normal colour vision are rendered monochromatic by night vision equipment and are able to obtain the required information from the instrumentation to operate the aircraft, it is reasonable to infer that a CVD aircrew member would also be able to obtain the same information from the same displays.

4.7 Maps

As with EFIS displays, CVD aircrew have significant experience in using aeronautical maps by day within the civil aviation community. As already mentioned aircrew do not simply come across a map in flight but study and prepare it before flight. They then track their progress along it in flight. Symbols and lines, whether coloured or not, should come as no surprise. Interestingly, the Australian Administrative Appeals Tribunal heard that CVD pilots may actually be at an advantage in using aeronautical maps in conditions of adverse lighting[73]:

> *"The maps carried by pilots for use in flight are frequently marked with coloured lines. A pilot who is a protan or a deutan probably has difficulty identifying the colours of lines, particularly red, in the subdued light of a cockpit at night. However, so too does a pilot with normal colour vision if, as is permitted, the colour of the cockpit lighting is red. In such a situation a pilot with defective colour vision may actually be at an advantage since, as Dr Samuel pointed out, a person who has never had very precise colour vision habitually seeks non-chromatic cues. On a map there are many cues in addition to the colours of particular lines. We have come to the conclusion that the inability of a pilot who is a protan or a deutan to identify quickly and accurately the colours of lines on maps does not result in a risk of his not being able to pilot his aircraft safely."*

In light of the evidence that CVD aircrew already utilise maps during daylight without issue and may actually be at an advantage in adverse lighting as they are less reliant on chromatic cues, there is no reason to consider a CVD aircrew less capable in map reading.

5. CLINICAL TEST METHODS AND THEIR RELEVANCE TO AVIATION

The full array of clinical CVD tests will not be revisited in this document as they are already well documented in the literature[74]. It is suffice to say that clinical CVD tests are intended to diagnose the presence and type of CVD. For this purpose they are very effective, generally exploiting colour confusion lines which have previously been discussed. Colour confusion lines however are deliberately avoided when designing actual applications whether that is in aviation, ground transport or entertainment systems. As already discussed, lighting and instrumentation display standards provide chromatic limits in this regard. As such, clinical tests bear little relevance to vocational demands.

Some clinical tests, such as the Farnsworth D15 test and the Nagel Anomaloscope, do quantify the severity of CVD. Again however, none of these tests provide an indication of how the individual will perform in any vocation, whether that is as aircrew or otherwise.

[73] Administrative Appeals Decision 5034, Denison and the Civil Aviation Authority. Administrative Appeals Tribunal of Australia.
[74] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.

Even lantern tests do not simulate any actual task performed in aviation. This has been stated by a number of bodies of work and is the reason that lantern tests are now being phased out across many jurisdictions[75]. The Farnsworth lantern for example, displays pairs of lights which fall on colour confusion lines for the various forms of CVD[76]. The test is thus effective in identifying CVD but is not targeted at determining the suitability of an individual for an occupation.

For many years an arbitrary pass mark has been applied to CVD clinical diagnosis tests. That pass mark provides a cut off between those who are considered by medical regulators to be fit to fly without restriction and those who should be subject to disqualification or restrictions. The previously mentioned signal gun test is an example. Despite having no relevance to modern commercial or military operations, it has been used in some jurisdictions to determine who is fit to progress from first officer to captain. Within New Zealand, the pseudoisochromatic plates and Farnsworth lantern have similarly been used to determine who may fly without CVD restrictions and who may not. Neither test is relevant to aircrew tasks[77].

What is also interesting is that there is no consistency in pass marks for CVD tests. Neither is there consistency in the tests applied across jurisdictions. While one regulator may place restrictions on an applicant who makes two errors in the Ishihara 38 plate test, another regulator may pass an applicant who makes eight errors. While an applicant may fail one test, that same applicant may pass a different test applied by a different regulator.

Consequently, there are aircrew limited by CVD clinical testing in one jurisdiction that fly all manner of operations under another. This inconsistency in test standards reinforces the view that clinical pass marks and testing methods are of questionable value and are unrelated to vocational performance.

5.1 Colour Assessment and Diagnosis (CAD) Clinical Test

The Colour Assessment and Diagnosis (CAD) clinical test is discussed in detail as it is a relatively new computer based clinical tool which has received considerable attention in the literature in recent years. The tool was developed by City University London. Exactly as the name suggests, the tool was designed for CVD diagnosis and determination of severity, not unlike the Farnsworth D15 test or the Nagel Anomaloscope. The test has since been adopted by the United Kingdom CAA and is being considered by several other regulators for use in assessing whether a candidate has adequate colour perception ability to crew an aircraft.

The CAD test requires a candidate to identify the movement of a pixelated square on a pixelated background. Candidates with varying levels and forms of CVD will have difficulty distinguishing movement of the square at various times during the test sequence, not unlike legacy clinical tests.

[75] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew – Part 1, United Kingdom Civil Aviation Authority, August 2006.
[76] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.
[77] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.

The CAD test is, in itself, no more representative of an aviation task than any other clinical test method for CVD. All clinical tests, including the CAD test, have the ability to identify the presence of CVD. Some, such as colour arrangement caps and the Nagel anomaloscope also have the ability to measure the severity of CVD. None have the ability to determine how CVD will affect the ability of a candidate in their chosen career, whether that is as a pilot or any other career. The CAD clinical test is therefore, in itself, nothing more than an alternative clinical test to the many clinical tests that are already available.

5.1.1 ADAPTION OF CAD TEST BY CITY UNIVERSITY FOR PILOT CANDIDATES

The University considered the precision approach path indicator (PAPI) as one of the few devices through which the conveyance of information by colour may be of importance to flight safety[78] [79]. The operation of the PAPI has already been discussed as have the redundancies of the system.

To reiterate, the PAPI light colours are, by design, selected so as to avoid colour confusion for CVD observers, conforming to SAE AS 25050A or equivalent standards. Additionally, the engineering specification for PAPI require white lights to be 2 – 6.5 times as intense as red lights[80] [81]. The PAPI conveys approach path information using both colour and brightness with the observer, whether CVD or colour normal, able to perceive the different PAPI signals as darker red or brighter white. Additionally, approach path information is available from the runway and approach light geometry[82] and approach instrumentation.

In adapting the CAD test for the assessment of aircrew candidates, City University London measured the performance of candidates on the CAD test and on a PAPI simulator that was also developed by the University[83]. It was thus accepted by the UK CAA that achievement of the prescribed pass mark in the CAD test may be considered to also be representative of an ability to read the University PAPI simulator without issue. This assumption is not challenged. Most certainly, if a candidate can achieve the prescribed pass mark on the CAD test, published data indicates the candidate will also have no difficultly in reading the City University PAPI simulator.

Four aspects of the validation process are however open to challenge. The University PAPI simulator was not representative of the colour or intensity of real PAPI lights. Rather the University PAPI simulator modified the colours of the signal lights to exploit lines of colour confusion. It also eliminated the secondary intensity cue that is designed into the real PAPI. Thirdly, simulator lights were only presented

[78] Paper 2006/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 2, United Kingdom Civil Aviation Authority, August 2006.
[79] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.
[80] Advisor Circular AC 150– 5345-28 Precision Approach Path Indicator (PAPI) Systems, Federal Aviation Authority, September 2011.
[81] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.
[82] Report FAA-AM-79-25, Runway Shape as a Cue for Judgement of Approach Angle, Federal Aviation Administration, November 1979.
[83] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.

for 2-3 seconds, after which the subject was required to state how many red lights had been shown. By comparison the real PAPI is continuously visible to the observer when interpreting the signal. Finally, the pass mark in the CAD test was adjusted so as to be conservative. A proportion of candidates who were able to read the City University PAPI simulator without error fall below the prescribed CAD pass mark[84]. As such the CAD test applies four levels of conservatism which result in a significant proportion of CVD candidates being excluded.

5.1.2 LIGHTING USED IN CITY UNIVERSITY PAPI SIMULATOR

The City University PAPI simulator modified the white signal such that the chromatic content was variable with changes of applied current and spanned colour confusion lines for CVD observers. This is the same principle exploited by legacy CVD diagnosis tools such as the Ishihara plate test and some lanterns. The shift in colour was such that the white light exceeded the range mandated by SAE AS 25050A for aviation signals. Interestingly, the 1931 CIE colour space diagram used by City University (Figure 5.1) also failed to meet SAE AS 25050A as it contained wider limits. For example the x axis limit for incandescent white in SAE AS 25050A is 0.54. For LED white the x axis limit in FAA Engineering Brief 67D is 0.44. The City University chart shows the limit as 0.56 while the variable current white light reached a value of approximately 0.57 – approaching yellow-orange, which may potentially be confused with red.

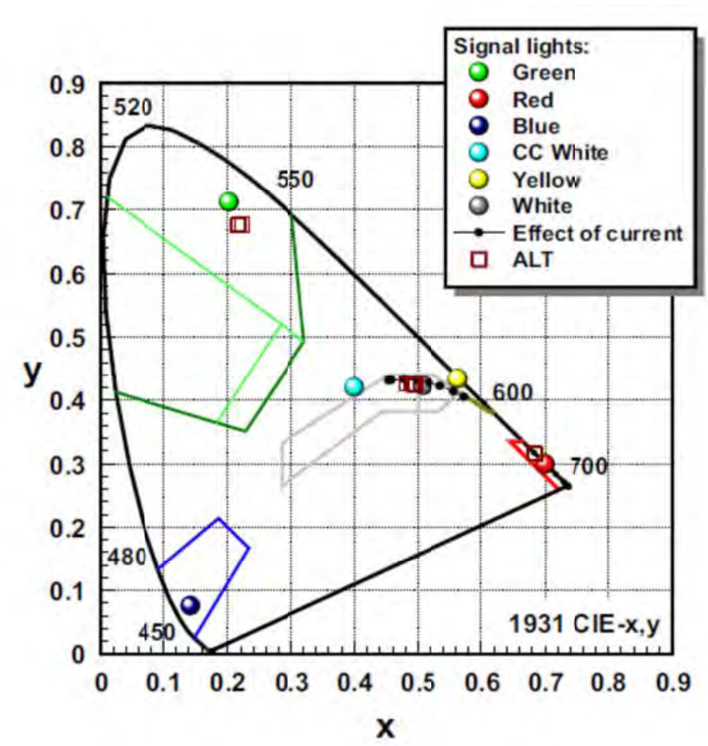

Figure 5.1 - 1931 CIE colour space diagram used by City University London showing the range of colours used. Note the white light, with current changes, varies in the x range from approximately 0.45 to 0.57

[84] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.

In addition to using colours which would be unacceptable in aviation lighting applications, the University also removed the intensity difference between the red and white lights that is a design feature of real PAPI[85]. Consequently, candidates were relegated to a colour recognition test for colours that were inherently confusing and not representative of aviation lights – not unlike clinical lantern tests.

Further deviating from the real PAPI, the University simulator only showed the lights for 2-3 seconds, after which the lights were extinguished, a buzzer sounded and the observer was then asked how many red lights had been displayed. By comparison, a real PAPI will display the signal lights continuously and so be visible to the subject at the time at which they are determining their approach slope. In the case of the University simulator, 11% of observers with normal colour vision made errors in naming how many lights had been previously displayed[86].

The City University PAPI simulator, used to calibrate the CAD test, is unrealistic of what is expected of aircrew when flying an approach. Use of the University PAPI simulator to develop a pass mark for the CAD test and hence judge the capacity of aircrew is therefore questioned. No explanation is provided by the University for using incorrect chromatic limits, eliminating brightness cues, limiting the viewing time or introducing a buzzer to the PAPI simulator.

Interestingly, despite eliminating intensity cues and using inherently more easily confused colours, CVD subjects performed well in the University PAPI simulator. The results are depicted in Figure 5.2. When asked to name whether sets of lights were all red or all white, 91.5% of CVD subjects made no errors across multiple test runs. The remaining 8.5% made few errors. Only two of the 117 CVD candidates achieved less than 90% accuracy with the worst performing subject achieving 80% accuracy. To quote City University[87]:

> *"Subjects do not often confuse reds with whites or whites with reds."*

[85] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.
[86] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.
[87] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.

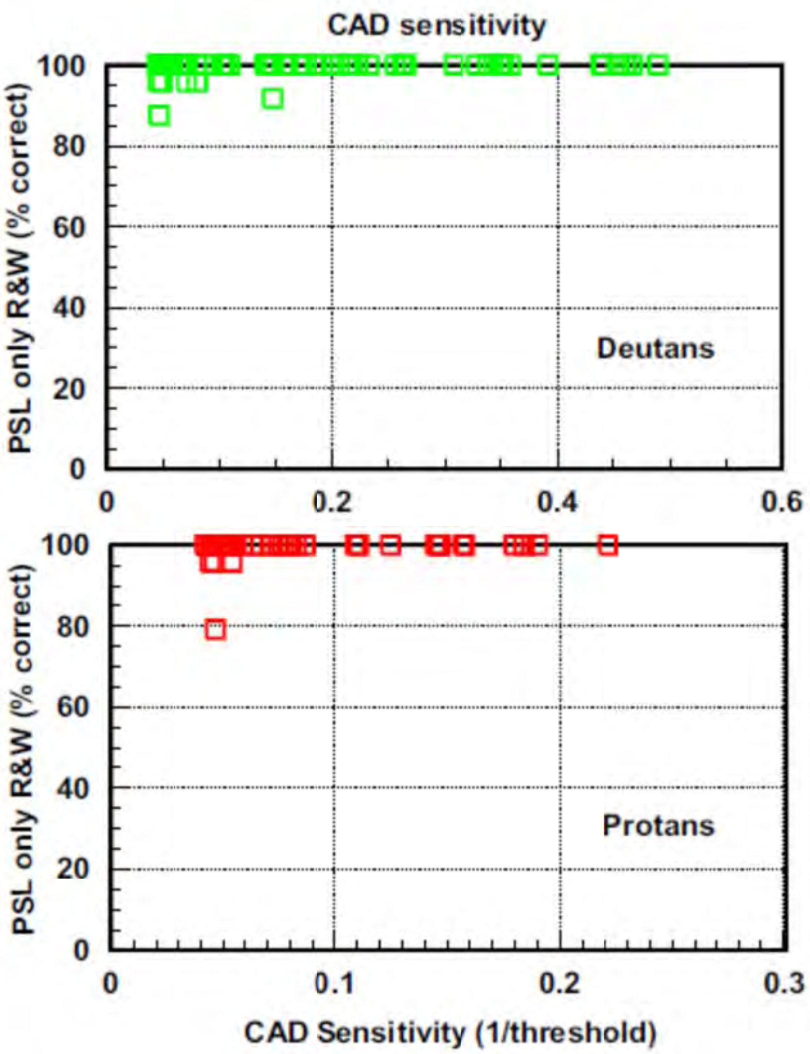

Figure 5.2 – Ability of protan and deutan subjects to identify red or white lights on the City University PAPI simulator. Each subject was presented with multiple test runs with 91.5% of CVD observers making no mistakes. The remainder achieved at least 80% accuracy.

5.1.3 *FEDERAL AVIATION AUTHORITY (FAA) PAPI SIMULATOR*

As already discussed, when examining the effects of changing from incandescent to LED lighting in the PAPI, the FAA developed their own PAPI simulator for use in clinical trials. The FAA simulator was intended to be realistic of a fielded PAPI, utilising real PAPI lenses (and hence colours) and did not totally eliminate intensity differences between the various lights, although it did reduce the intensity difference such that the white light was only 20% brighter than the red light in order to be conservative. In that study, there was no difference in performance between candidates with normal colour vision and those with CVD when using incandescent lights. The move to LED technology saw protan, deutan and tritan CVD candidates achieve perfect scores in the PAPI test[88].

[88] Report DOT/FAA/AM-14/6, Usability of Light Emitting Diodes in Precision Approach Path Indicator Systems by Individuals with Marginal Color Vision, Federal Aviation Administration, May 2014.

5.1.4 ADJUSTMENT OF PASS MARK BY CITY UNIVERSITY IN THE CAD TEST

In determining a pass mark for pilot applicants on the CAD test, the value of 12 standard normal units (12 SN) was selected for protan candidates and a value of six standard normal units (6 SN) was selected for deutan candidates. In the case of protan candidates, 50% of candidates passed the University PAPI simulator, however only 33% achieved the prescribed CAD pass score. In the case of deutan candidates, 44% passed the University PAPI simulator but only 38% achieved the prescribed CAD pass mark[89]. It can be seen that the CAD pass marks were thus conservative.

In considering the effect of using a modified white light in the PAPI simulator to better represent the use of LED lighting, the discrepancy was even greater with still more CVD candidates passing the University PAPI simulator[90].

City University states that it considered those candidates who passed the University PAPI simulator but who did not meet the prescribed pass mark for the CAD test would have difficulty in other aspects of piloting aircraft[91]. Presumably this refers to the use of instrumentation, maps and navigation aids. This suggestion is made without basis and is at odds with other work in the same project which identified the PAPI as the most significant task involving colour in aviation. Moreover, it appears to ignore the fact that CVD pilots already fly in other jurisdictions using the same instrumentation, maps and aids by day and night.

5.1.5 CONCLUDING COMMENTS ON THE CAD TEST

The CAD test is undoubtedly a useful tool for identifying and numerically quantifying the colour vision ability of individuals. However, it does not appear to add in the assessment of vocational performance from pre-existing methods such as the Farnsworth D15 colour arrangement test and the Nagel anomaloscope. Both systems are already available, with the colour arrangement test being accessible for minimal cost at local optometrists.

It is unclear why City University London promoted their own CAD test for the assessment of aircrew applicants as opposed to validating a pre-existing test against the simulated PAPI. Granted the CAD test is a repeatable clinical test which is nicely packaged within a computer system. That said, it is comparatively expensive and not readily accessible. The business case for change is therefore questioned.

5.2 Alternative to clinical testing

Clinical tests of all forms are designed to diagnose the presence and, in some cases, the severity of CVD. They are, by design, difficult for a CVD subject to complete.

[89] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.

[90] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.

[91] Paper 2009/04, Minimum Colour Vision Requirements for Professional Flight Crew–Part 3, United Kingdom Civil Aviation Authority, May 2009.

Clinical testing does not however replicate operational tasks performed by aircrew and so is a questionable method by which to gauge vocational performance.

NATO has recommended an alternative method of candidate assessment based on the International Classification of Handicap (ICH)[92]. NATO recommends that CVD assessments should evaluate the capacity or competency of an individual to crew aircraft and not merely identify the presence of CVD or their ability to complete clinical diagnosis tests.

NATO has raised PROCOPAT software as one such test, which assesses the candidate on a combination of coloured puzzles, coloured mazes and aeronautical images[93]. The relevance of the coloured puzzles and mazes to aviation is however not clear and the system does not appear to have been adopted by any nations. An alternative may be a simulator exercise analogous to the “monkey box” flight screening exercise traditionally used to check for candidate coordination and motor skills. Alternatively a desk top trainer exercise may be developed for use.

6. DISPENSATIONS FOR CVD AIRCREW

Within many military and civil jurisdictions, including both New Zealand civil and military, waivers have been provided to allow CVD individuals to enter or remain within the aircrew population. Such waivers are known to have occurred in the naval environment as well. The process of issuing waivers has, in some circumstances, been structured and based on a formalised process. In other cases it has been ad hoc in nature.

A reportedly high profile case was that of the NASA chief astronaut and pilot of a number of space flights following a career with the US military[94]. Within the New Zealand civil aviation community the issue of waivers has been ad hoc and has been at the whim of medical staff at the time. Many pilots were issued with dispensations to allow passenger operations, night and IFR flight because they satisfied clinical test criteria that are applied in other nations such as, for example, the Farnsworth D15 test. In other cases, CVD pilots were issued dispensations after demonstrating competency in flight to a flight examiner. In other cases, CVD pilots were issued dispensation after completing arbitrary tasks such as signal gun tests. Similar waivers have been issued in other jurisdictions. The FAA has, for example, issued Statements of Demonstrated Ability (SODA) to those who have demonstrated competency in practical flight tests.

6.1 Military aviation

Within the military, waivers have also been applied to CVD pilots. Surveys have found very senior aircrew with many thousands of hours experience to be operating with CVD. Research determined that colour vision testing used in the US military during the latter half of the last century was ineffective in screening for CVD. The US

[92] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.
[93] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.
[94] Santos, J., Congenital Deutan Defects of Color Perception in Mission Specialists, 1 Dec 1998.

Army estimated that approximately 4.5% of pilots have CVD[95]. CVD was not identified as a factor in any army incidents or accidents.

6.2 Growth of a cohort

The consequence of these waivers and variable screening procedures and standards has been the growth of a cohort of CVD pilots flying within many jurisdictions at all levels of operation, from captaining air transport operations in the largest airliners through to flight instruction and military operations. These CVD pilots have, consistent with their peers, been subject to flight tests, line checks and renewals throughout their flying careers. There is no record to indicate that any have suffered difficulty or posed a risk to flight safety. To the contrary, discussions with individuals, medical staff and flight examiners affirmed the ability of the individuals concerned.

6.3 Parallel to submariners

The same positive outcome has been reported for CVD submariners. In times of critical need for specific specialties, waivers have occurred:

> "*During the past three to four years, three men have served on submarines under a waiver of the colour vision requirement. The Commanding Officer and other supervisors reported that the colour vision deficiency did not degrade the performance of the colour defectives aboard the ship. The colour defectives themselves, however, did report occasional difficulty in correctly identifying navigational lights on initial observation, but stated that they exercised extreme diligence in keeping their eyes on the lights as the target neared. It is felt that a major reason for the lack of severe problems lies in the fact that the men were aware of their special status. It cannot be emphasized too strongly that the man who admits his defect, realizes he cannot distinguish colours and seeks help does not represent the same hazard as the man who hides his defect and attempts to perform normally*" [96].

7. OVERSEAS EXPERIENCE OF CVD PILOTS

7.1 Australia

Australia represents the nation closest to New Zealand with the most relaxed stance on CVD pilots. Since 1989, civilian CVD pilots in Australia have been subject to minimal restrictions, being able to pilot all types of aircraft on single pilot commercial operations, day and night, under visual and instrument flight rules, including the carriage of fare paying passengers. The only restrictions that have applied to CVD pilots have been:

- No ATPL privileges, precluding CVD aircrew from captaining multi crew operations (typical of larger airline operations).

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[95] Report 65-2, Colour Vision Deficiencies in Army Fliers, United States Army Aeromedical Research Unit, April 1965.
[96] Santos, J., Congenital Deutan Defects of Color Perception in Mission Specialists, 1 Dec 1998.

- Limited to Australian airspace unless the regulatory authority of the second country is consulted.

Upon passing the signal gun test, all restrictions were removed. However, more recently in 2015, ATPL privileges were extended to first officer and flight examiner Mr John O'Brien despite him being unable to pass the signal gun test or indeed any clinical CVD test at all. Given the lack of relevance of the signal gun to air transport operations, excusing the individual from the signal gun test is logical. However the Administrative Appeals Tribunal did also consider the trans-cockpit gradient associated with moving from the role of first officer to captain of a high density air transport operation. The Tribunal found that there was no increased risk to flight safety caused by his CVD[97].

Since the lifting of his restrictions, Mr O'Brien has passed further intensive training and testing and has become qualified as a Captain and Instrument Rating Flight Examiner on Dash 8 turboprop aircraft and simulators, illustrating that an inability to pass clinical testing does not translate to an inability to meet operational demands.

In the course of the O'Brien case it was advised by CASA that there are approximately 400 CVD commercial pilots operating in Australia. Additionally, there are others who operate privately and those who have passed the signal gun test and are no longer considered having CVD despite failing all clinical testing. Based on typical flying rates for commercial pilots, this group of 400 pilots would now be flying in excess of 300,000 hours per year. Over the 26 years since CVD restrictions were relaxed, the CVD commercial pilot population of Australia may be expected to have flown in the order of four million flight hours without incident[98].

Throughout the period of operations by CVD pilots in Australia, these pilots have been subject to flight tests, line checks and renewals in line with the broader pilot population. There is no evidence to indicate that the CVD pilot population has performed any differently to the wider pilot population.

7.2 North America

Canada and the United States have comparatively lenient clinical examination standards, so allowing a proportion of CVD pilots to fly without restrictions. Additionally, candidates may demonstrate competency through practical flight tests. Current numbers of CVD pilots operating in other nations are not immediately available, however over the period 1974 to 1976, CVD pilots who were operating without restrictions in the United States increased in number from 5,157 to 6,861. A 1979 study found no difference in the accident rates of this population when compared to the general pilot population. Additionally, of those accidents that did occur, none were associated with CVD[99].

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[97] Administrative Appeals Decision 2014/1361, O'Brien and the Civil Aviation Safety Authority. Administrative Appeals Tribunal of Australia.

[98] Calculated on the assumption of an average flying rate of 750 hours per commercial pilot per annum. It is assumed that the pool of 400 CVD pilots grew linearly from none over the 26 year period.

[99] Report FAA-AM-79-19, The 1976 Accident Experience of Civilian Pilots with Static Physical Defects, Federal Aviation Administration, 1979.

Both Canada and the United States apply relatively lenient pass criteria to clinical testing. As such many aircrew that would be considered to be CVD in other jurisdictions are considered colour normal in North America and do not need to undertake the waiver process.

8. THREAT AND ERROR MANAGEMENT

The International Civil Aviation Organisation (ICAO) has fostered the concept of Threat and Error Management (TEM) within aviation[100]. Developed by Delta Airlines and Texas University, TEM mandates a periodic proactive Line Operations Safety Audit (LOSA) to identify threats such that countermeasures may be put in place to prevent incidents and accidents occurring[101]. Within the TEM construct, an error represents an inappropriate response by a crew member to a threat which then may lead to an undesired situation. For example, a threat could be an incorrect PAPI indication, as has already been discussed, which may occur in conditions conducive to moisture or dust formation on the PAPI lens. An error would the failure by the operator and crew to utilise redundant procedures to confirm approach path, leading to an approach path excursion. TEM can be considered to be the aviation equivalent of resilient engineering or defensive driving.

United States, Canadian, Australian and New Zealand airlines have been at the forefront of adopting TEM. In LOSA conducted over the period 2002-2006, 19,053 threats were identified as were 13,675 errors[102]. No literature could be found relating colour vision deficiency to threats, errors or incidents despite these countries having populations of CVD pilots.

9. ACCIDENTS AND INCIDENTS INVOLVING AIRCREW WITH CVD

9.1 Airspace infringements

Interestingly there is a near absence of incidents or accidents in which CVD has been noted as a contributing factor. In the United States in 2004 and 2008 there were two occasions on which it was reported that CVD pilots entered controlled or restricted air space without the necessary clearance[103]. Reliable figures could not be found for New Zealand but each year in the UK there are approximately 800 air space infringements by the general pilot population[104]. In one summer, 11 air space infringements were reported for Queenstown[105]. This places the two recorded

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[100] ICAO Manual 9803, Line Operations Safety Audit, International Civil Aviation Authority.
[101] Merritt, A. and Klinect, J., Defensive Flying for Pilots: An Introduction to Threat and Error Management, University of Texas, 2006.
[102] Merritt, A. and Klinect, J., Defensive Flying for Pilots: An Introduction to Threat and Error Management, University of Texas, 2006.
[103] Watson, D., Submission to the Administrative Appeals Tribunal in the case of O'Brien and the Civil Aviation Safety Authority, 2013.
[104] Airspace and Safety Initiative Flyer, Airspace Infringements Working Group, United Kingdom Civil Aviation Authority, April 2007.
[105] 11 Infringements at Resort Breach Airspace Rules, http://www.odt.co.nz/news/queenstown-lakes/197642/11-incidents-resort-breach-airspace-rules, Otago Daily Times, 14 Feb 2012.

infringements by CVD pilots in the United States into perspective. Invariably such infringements are likely to be the result of poor flight planning resulting in a pilot becoming unsure of their position. No other incidents involving CVD pilots could be found.

9.2 Fed Ex 1478 Collison with trees on landing

The only accident known for which CVD was named as a potential contributory factor was that of Fed Ex 1478, a Boeing 727 which collided with trees short of the runway in 2002. In that incident three pilots were on the flight deck. One, the first officer, suffered CVD but had passed the necessary clinical lantern test to be issued an unrestricted medical. The other two pilots had normal colour vision. The aircraft was on a visual approach at night and descended in a non-stabilised approach to descend short of the runway. The NTSB listed CVD as a contributory factor beyond crew fatigue and use of incorrect procedures[106]. The reason all three crew failed to see or react to what should have been four red PAPI lights, which would be expected of a low approach, has never been adequately explained.

It has been suggested that the PAPI itself gave false indications, as the Australian Defence Science and Technology Organisation (DSTO) and FAA advised was possible, in conditions conducive to condensation or dust formation on the lens[107] [108] [109]. As already discussed, it is reported that under such conditions the red PAPI signals may be diffused with the adjacent white signals to appear whitish-pink. Two days after the accident, the National Air Traffic Controllers Association provided a submission to the NTSB advising that all four PAPI light boxes displayed a high level of particulate contamination. The FAA inspected the units some three months later, at which point they were identified as being very clean. This suggests the units were cleaned subsequent to the accident[110] .

It is interesting to note that the FAA also issued a Certification Alert five months after the accident, warning that condensation could provide false PAPI indications. Tallahassee airport, where the Fed Ex accident occurred, subsequently rewired their PAPI system in accordance with the recommendations of the Certification Alert to prevent condensation formation[111]. False indications due to the formation of condensation in the early morning and/or particulate contamination remains a plausible alternative explanation noting the PAPI was remotely activated by the Fed Ex aircrew just three minutes prior to the accident and the system had not had

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[106] Aircraft Accident Report AAR-04/02, Collision with Trees on Final Approach Federal Express Flight 1478, Tallahassee, Florida, July 26, National Transportation Safety Board, 2002.
[107] Pape, A. and Crassini, B., The Puzzle of the Crash of Fedex Flight 1478: Implications for Colour Vision Standards in Aviation in Journal of the Australian Society of Aerospace Medicine, 2013, 8:28-31.
[108] Systems Report 25, Hazards of Colour Coding in Visual Approach Slope Indicators, Defence Science and Technology Organisation, Department of Defence, Australia,1981.
[109] Report DOT/FAA/CT-82/153, Evaluation of Precision Approach Path Indicator (PAPI), Federal Aviation Authority, April 1983.
[110] Docket 296596, National Transportation Safety Board, 2002.
[111] Certification Alert 02-08, PAPI Operation, Federal Aviation Authority, 12 Dec 2002.

adequate time to warm and clear condensation as is required for reliable indications to be produced.[112]

Placing this accident in context, other accidents have also occurred in which aircraft have descended below the approach path. Perhaps the most recent high profile accident was Asiana flight 214 which descended short of the runway in fine weather at San Francisco in 2013 due to crew mismanagement[113]. Another was Air France flight 5672 which descended in a non-stabilised approach in poor weather. These accidents, involving aircrew with normal colour vision, indicate that factors other than CVD may be responsible for such accidents even when the PAPI lights or instrumentation are visible to crew.

9.3 F-4 Phantom spatial disorientation

Raised in literature is the loss of a McDonald Douglas F-4 Phantom aircraft by the USAF while being flown by a pilot with CVD[114]. It is reported that the pilot suffered spatial disorientation in which he perceived a midair collision was imminent and ejected. It is not clear how CVD is connected with the spatial disorientation that the pilot suffered however it is known that in the period 1971-1985, the USAF suffered 535 accidents as a result of spatial disorientation. Of these accidents, 282 involved F-4 aircraft, suggesting that this aircraft type was prone to inducing spatial disorientation in pilots[115]. Given the ineffective CVD screening programme of the US military at that time it is not surprising that eventually a CVD pilot would be operating an accident aircraft. Given that presumably all other accidents involved pilots with normal colour vision, as CVD was not mentioned with regards any other accidents, the link to CVD must be considered tenuous.

Despite consulting regulators from New Zealand, Australia, North America and Europe, no other occurrences could be found in which CVD was considered contributory. A similar review by the FAA found an absence of accidents attributable to CVD[116].

Interestingly there is also an absence of accidents or incidents attributable to colour perception when crew were wearing monochromatic night vision equipment. This suggests that individuals, when appropriately trained, adjusted and aware of the limitations of their colour vision, are capable of operating safely. This reinforces the previous comments made concerning CVD in submariners.

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[112] Pape, A. and Crassini, B., The Puzzle of the Crash of Fedex Flight 1478: Implications for Colour Vision Standards in Aviation in Journal of the Australian Society of Aerospace Medicine, 2013, 8:28-31.

[113] Aircraft Accident Report AAR-14/01, Descent Below Visual Glidepath and Impact with Seawall Asiana Airlines Flight 214, San Francisco, California, July 6, National Transportation Safety Board, 2013.

[114] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.

[115] Vasconcelos, M., Civil Airworthiness Certification: Former Military High Performance Aircraft, Federal Aviation Authority, September 2013, Pg 2-313.

[116] Report FAA-AM-79-19, The 1976 Accident Experience of Civilian Pilots with Static Physical Defects, Federal Aviation Administration, 1979.

10. CONCLUSIONS

The rationale for adopting clinical test methods for CVD and restricting the privileges of CVD aircrew in the period following World War One can be understood. In that era, control of aircraft relied upon the use of ground based signal lamps and flares. Collision avoidance at night relied upon sighting of coloured navigation lights on other aircraft. Regulation and hence consistency of colours used in signalling and lighting devices was less mature and variation was likely. In short, there was a reliance on the use of colour coded information.

The past century however has seen great advancement of technology and also the regulation of technology used in aviation. Where coloured ground lamps and flares once provided the method of communication between aircraft and controllers, there are now radios, transponders, cell phones, satellite phones and data messaging systems. Where once only small coloured navigation lights assisted collision avoidance at night, there now exists radio communications, high intensity strobe lights, rotating beacons, landing lights, tail illumination and automated collision avoidance systems, all effective at great distances in all weather conditions. Regulations and standards now exist to precisely define the chromatic content of coloured lights and displays such that they may be comprehended by all individuals regardless of CVD status or other visual aids and eye protection.

Multiple reviews by the Administrative Appeals Tribunal of Australia, as well as relevant research by the United Kingdom CAA and United States FAA and others have consistently demonstrated that CVD aircrew can perform operational tasks as competently as those with normal colour vision. The 26 years of incident free commercial operations by CVD pilots in Australia, day and night, VFR and IFR on all operations including air transport and all aspects of general aviation provides a significant pool of empirical evidence to support this conclusion. The significant number of CVD aircrew operating in the military and civil aviation communities of many countries, including New Zealand, further supports this conclusion.

Clinical tests diagnose the presence and, in some cases, the severity of CVD. They are, by design, difficult for a CVD subject to complete. Clinical testing does not however relate the deficiency to tasks performed by aircrew and so is considered an unsuitable method by which to gauge vocational performance. In some jurisdictions this has seen waivers provided to aircrew who could demonstrate the ability to complete operational tasks.

NATO has recommended formalising an alternative method of candidate assessment based on the International Classification of Handicap (ICH)[117]. NATO recommends that CVD assessments should evaluate the capacity or competency of an individual to crew aircraft and not their ability to complete clinical diagnosis tests. This report supports that recommendation and notes that such assessments are already in use by a number of regulators.

[117] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.

11. RECOMMENDATIONS

11.1 Demonstration of capacity by flight testing for civil aircrew

In civil aviation it is recommended that candidates who are diagnosed with CVD by clinical screening tests should be afforded an opportunity to demonstrate operational competence in a practical flight test. This is consistent with practical flight testing already used for the issue of aircrew licences. Practical flight testing is also already used in some jurisdictions when assessing CVD pilots and for other medical issues such as loss of hearing or limbs.

The satisfactory completion of a competency based assessment, and indeed multiple such assessments as they progress through their career, is considered satisfactory to provide the regulator with confidence that the individual has the required capacity and competency to crew an aircraft.

11.2 Demonstration of capacity by simulation for military aircrew

For military aircrew the capacity of candidates to perform operational tasks should be determined prior to training using a suitable simulation based test which reflects operational demands. Use of a practical flight test is considered uneconomic for the military as this would require the expenditure of resources to provide training to the candidate.

NATO has raised PROCOPAT software as one such test, which assesses the candidate on a combination of coloured puzzles, coloured mazes and aeronautical images[118]. The relevance of the coloured puzzles and mazes to aviation is however not clear and the system does not appear to have been adopted by any nations. An alternative may be a simulator exercise analogous to the “monkey box” flight screening exercise traditionally used to check for candidate coordination and motor skills. Alternatively a desk top trainer exercise, similar to a flight simulator exercise, may be developed for use.

11.3 Summary of CVD test process for both civil and military applicants

To incorporate both primary and secondary screening as well as the option for demonstrating practical competence, a three stage screening process is recommended.

Stage 1 - Primary screening. During an initial medical assessment, candidates shall be examined using an Ishihara pseudo isochromatic plate test. Pass criteria defined by the FAA for the Ishihara test would apply. Should a candidate pass this screening no further screening is required.

Stage 2 - Secondary screening. Should a candidate not pass primary screening, secondary screening should utilise tests that are already accepted by various other reputable military and ICAO regulatory authorities. Examples include the Farnsworth, Holmes Wright and Giles Archer lanterns, Farnsworth D15 test or CAD test. A pass

[118] Technical Report 16, Operational Colour Vision in the Modern Aviation Environment, NATO Research and Technology Organisation, March 2001.

in any one of these tests may be considered to indicate the candidate has a mild deficiency which is not of significance to their ability to crew an aircraft.

Stage 3 - Practical flight test or simulator exercise*.* Candidates who fail primary and secondary clinical screening should be afforded an opportunity to demonstrate their capacity to safely operate during a practical flight test or simulator exercise as appropriate.

This three tier test regime, which essentially serves to formalise and standardise the issue of waivers for those who fail clinical CVD testing, is entirely consistent with the recommendations of NATO and those test regimes in use by some other civil jurisdictions.

11.4 Further research

It is recommended that further research be undertaken to identify any unique tasks performed by NZDF aircrew and how those tasks may be simulated and/or tested in a routine vocational assessment for applicants with CVD. This assessment should consider:

- Pilots
- Flight engineers
- Air warfare officers and air electronic operators
- Parachutists
- Unmanned aerial system operators
- Helicopter crewpersons
- Loadmasters

Any unique colour vision requirements for NZDF ground personnel associated with aircraft maintenance should be determined such that a vocational assessment can be developed for applicants with CVD.

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13. ABSTRACT

Colour Vision Deficiency (CVD) is a condition that results in individuals being unable to distinguish differences between certain colours. The condition is most commonly inherited, affecting approximately 8% of men and a smaller proportion (0.5%) of women. Exclusion of applicants with CVD reduces the number of potential candidates available for selection as aircrew.

A continuum exists in the severity of CVD. At the most benign end of the continuum an individual may have near normal colour vision. At the opposite extreme, an individual may be monochromatic. The latter is extremely rare.

The compatibility of CVD with crewing aircraft is assessed by medical personnel using clinical diagnosis tests. These clinical tests were developed specifically to detect the presence, nature and severity of CVD. No clinical tests yet provide a measure of vocational performance in operating an aircraft.

Despite the lack of relevance to vocational performance, arbitrary pass marks have been assigned to clinical tests such that a failing candidate will either be subject to operational restrictions or excluded completely. The prescribed clinical tests and associated pass marks vary considerably between regulators. While an individual may be subject to no restrictions in one jurisdiction, they may be excluded in another.

In many civil and military populations, waivers have been given to CVD subjects who demonstrated competency in an operational environment. In some cases waivers were issued simply to achieve intake quotas. There is no record of such candidates suffering difficulty on operations as a result of their CVD. To the contrary there is much evidence to indicate that candidates with CVD, when aware of their condition, have been able to perform operational tasks to the required levels of competence.

This report presents and discusses available literature which indicates that aircrew with CVD are able to operate safely and effectively. The evidence raises questions about the suitability of current clinical test regimes as a means of restricting or disqualifying applicants. Consistent with the findings of NATO and the practice of some regulators, it is instead recommended that a practical or operational check, to identify practical handicaps as a result of CVD, is a more relevant and fair method by which to determine whether an applicant can safely crew an aircraft.

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