AVIATION COLOUR PERCEPTION STANDARD: A TIME TO RE-ASSESS[1].

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With the publication in the April issue of AVMEDIA of the article by Dr. Barry Clark on the subject of the aviation colour perception standard (ACPS), it is indeed an appropriate time to address this matter from an opposite perspective. My interest in colour vision is a personal as well as a professional one, being a colour-defective (deuteranopic) medical practitioner, and the holder of an Australian CPL and Command (multi-engine) Instrument Rating. I had the honour in the late eighties of leading the appeals against the standard in the Administrative Appeals Tribunal in two landmark cases[2] that forced a major de-restricting of colour-defective pilots in their civil aviation pursuits in Australia.

Dr. Clark's paper is indeed an excellent tutorial on the clinical types of colour-defective vision and on the test methods available for the quantification of those clinical types. But his foray into the field of aero-medical colour vision requirements is flawed. He is still fighting yesterday's fight. Firstly, it is extremely dated, relying on data from old studies, from an era preceding the significant recent advances in perception psychology and neuro-physiology of perception. For instance, it is now widely recognized that neural processing of visual stimuli involves complex information processing, beginning at the retina and extending throughout the visual pathway to the primary visual cortex and beyond. This complex processing involves, it has been proposed, the segregated analysis of aspects of visual stimuli such as luminance, wavelength, retinal disparity, motion and form. The retina, with its sixteen million cones is but a part of a highly complex structure involving billions of neurons that transform light stimuli into the meaning and structure through which we perceive and respond to our complex environment.

Dr. Clark advances his essentially political views with disregard for such advances in knowledge. Not only has he not considered the implication of these new insights into the physiological basis of visual perception with respect to simple perceptual tasks, further still he has not considered the implications for complex tasks, such as piloting an aircraft.

Secondly, his selection of data is selective. He all but ignores the AAT cases to which I refer, and which have so dramatically influenced the implementation of the ACPS in this country, and indirectly in others.

Considered together, these cases represent the most comprehensive review ever conducted anywhere in the world of the ACPS. There is a link from the AOPA web page at **Error! Bookmark not defined.**http://aopa.com.au to the text of the corresponding decision documents. Since these pivotal decisions, the Australian Civil Aviation Safety Authority, under its various previous names, has issued waivers against the standard, up to and including the CPL, subject to an "Australian airspace only" endorsement. In the years since 1989 there have been significant numbers of

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[1] This paper has been submitted to the Office of Aviation Medicine in response to the call from Dr. Jeff Brock, the Director, for submissions on the Aviation Colour Perception Standard

[2] The cases referred to are the following:

- Re: HUGH JONATHAN DENISON And: CIVIL AVIATION AUTHORITY No.V89/70 AAT No. 5034 Air Navigation 10 AAR 242
- Re: ARTHUR MARINUS PAPE And: SECRETARY, DEPARTMENT OF AVIATION No.V87/494 AAT No. 3821 Air Navigation
- Re: ARTHUR MARINUS PAPE And: SECRETARY, DEPARTMENT OF AVIATION No.V85/297 AAT No. 3321 Air Navigation.

colour-defective pilots applying for medical certificates to allow the exercise of ATPL privileges. On a case by case basis, the Office of Aviation Medicine has granted some of these requests, sometimes with and sometimes without, specific weight and airspace restrictions. In all cases, the applicants have had to demonstrate extensive and outstanding levels of experience.

Through Dr. Jeff Brock, I have been briefed on international meetings he has attended where the ACPS has been on the agenda. I am indebted to Jeff for his cooperation in this matter. It is clear from these briefings that there is no international consensus on this issue. Indeed, the gap appears to be widening between the Europeans on the one hand and the USA, Canada and Australia on the other. This gap, I suggest, is a reflection on the more autocratic nature of the European regulators. There is no instrument in Europe equivalent to our Administrative Appeals Tribunal, and the European AOPA bodies are far less pro-active than is Australia's. The opportunity, therefore, to force independent review of standards such as the one under discussion is severely limited in the European environment.

Dr. Clark's arguments in favour of the ACPS, which are typical of those used by proponents of the standard, may be summarized as follows:

1. Colour is used extensively in the aviation environment, both inside and outside the cockpit, to code important information.
2. The use of colour enhances the performance (in both speed and accuracy) of tasks and object recognition for colour normal observers.
3. Colour-defectives are less able than colour normal users to use the colour-coded information as reliably or as speedily.
4. Restricting the benefits derived by colour normals from the use of colour coding, in order to accommodate colour-defectives is not a practical proposition.
5. Colour-defectives should therefore be screened out of the user population by rigorous colour vision screening and testing.
6. The Aviation Colour Perception Standard should thus be vigorously maintained.

Dr. Clark states that "colour coding is ubiquitous in aviation, with many cases of functional colour coding". In support of this broad generalization, he provides an extensive list, which is quoted verbatim:

1. Anti collision beacons and strobes are red or white.

2. Navigation lights are red, green and white.

3. Rotating/flashing beacons are red and/or blue on ground emergency vehicles.

4. Airport ground support vehicles have amber rotating beacons, along with red tail and brake lights, and amber turn signals, and white reversing lights used by road vehicles in general.

5. Red, amber, white, green and blue lights are used on runways, taxiways and parking areas.

6. Obstruction lights are usually red.

7. Visual landing aids may include red, amber, yellow, green and white lights.

8. Cockpit and cabin lighting in military aircraft may be one of red, white, green, NVG-compatible blue-green (Type A) or white (Type B) systems, or a mix of any of these.
   Conventional panel instruments often carry coloured numerals, arcs and sectors, typically red, yellow, white, green or red.

9. Attitude and Directional Indicators may have brown and blue hemispheres.

10. Annunciator panels carry red warnings and amber cautions.

11. EFIS displays may use white, red, green, amber, blue, magenta, as sometimes brown, yellow, blue-green, violet, purple, pink and mauve.

12. Air to air refueling displays on the tanker exterior use red, amber and green lights.

13. NVGs at present have a monochrome green display that leaves a brown after-image.

14. Aviation maps and charts are often printed in four or more colours chosen from red, brown, amber, yellow (infrequent), green, blue and purple, with black/white backgrounds and delineations.

Significantly perhaps, he does not mention the tower signal gun (Aldis Lantern), which employs red, green and white to convey instructions to non-radio aircraft. This use of colour forms the basis of the "practical test" used in the USA to allow waivers against the standard.

Apart from the purely military items (NVGs and refueling tankers), the above list is essentially the same as that which the AAT was asked to consider in 1989. The AAT decision documents referred to above summarize the evidence presented to it in relation to each of the listed items. It is important to stress that in arriving at its decision, the AAT considered evidence contained in most of the references that Dr. Clark used in preparing his paper (but which were not published with the paper). I find it most telling that Dr. Clark makes only the tiniest direct reference in his paper to the entire AAT review of the colour perception standard, so conscientiously and painstakingly performed.

The above list is typical of many in written papers devoted to justifying the standard. In visual presentations, a similar but cruder device has been employed. I recall a presentation at one of the DAME seminars some years ago where a well-known aviation ophthalmologist flashed some colourful and dramatic slides of military jets and complex, multi-coloured, instrument panels. This was followed by the statement that "clearly you would be lost in this environment if you were a colour-defective." The entire exchange lasted no more than a minute or two. The fate of such ad-hoc testimony in a courtroom is not difficult to predict.

Dr. Clark makes no attempt to define any aspect of or to explain the meaning of the terms he uses. For instance, the terms "colour coding" and "functional colour coding", clearly pivotal to any argument on this subject, are neither defined nor explained. Instead, the reader is left to be swayed by the briefest excerpts from a very lengthy bibliography, whose word count alone is over 1700 words, but which is not published alongside the article. Many of the references were subjected to analysis, however, in the AAT cases already referred to. Many were found to be entirely irrelevant to the matter under contention. Others were found to be poor excuses for scientific investigation.

Of special note in the context of Dr. Clark's paper is his use as a reference of the work by Cole and Macdonald [3]. Dr. Clark repeats the claim that this work demonstrated that:

"Colour vision deficients are slower than colour normals at responding to redundantly colour-coded EFIS displays, and they make more errors. Protanopes are especially disadvantaged in responding to red 'fail' messages".

[3] Cole, B.L. and Macdonald, W.A. (1988) Defective colour vision can impede information acquisition from redundantly colour-coded displays. *Ophthalmic and Physiological Optics, 8, 198-210.*

He would, no doubt, be aware of the severe criticism this project received from expert witnesses and admissions by the authors themselves that the research was technically flawed. The Cole and Macdonald papers emerged from the AAT discredited. The work had serious deficiencies with respect to: candidate selection; failure to properly match groups in terms of age and educational backgrounds; and the conclusions drawn were not supported by the data. In addition, the simplistic tasks the subjects were required to perform bore no resemblance to the practical purpose for which the equipment under examination was intended. The Cole and Macdonald[4] papers would make an excellent exercise for students of scientific method.

That Dr. Clark was not persuaded by the eventual outcome in the AAT is clearly evidenced in his scant reference to these important cases. His one reference to them is quoted as follows:
" In Australia, six errors with the modified Farnsworth lantern was once the upper limit for civil night flying eligibility. However, an Administrative Appeals Tribunal case in 1989 by an emigrant commercial pilot from New Zealand resulted in dichromats becoming eligible to hold Australian commercial pilot licences but not airline pilot licences".
Even this short deference is factually wrong, which is surprising, given Dr. Clark's extensive personal participation at the hearing. Denison was then and is still in fact an Australian citizen, not "an emigrant commercial pilot from New Zealand". The reduction of the significance of these landmark hearings to a few lines betrays the bias that is evident in Dr. Clark's public contribution to the debate.

COLOUR CODING

To determine the meaning and value or otherwise of "colour coding" in Dr. Clark's "ubiquitous" list quoted above, the reader should first determine exactly what the term means. This defining step, avoided by Dr. Clark, is essential to progress any argument.

Firstly, the definition of the term "code" (from Webster's dictionary) could be:

- ANY SYSTEM OF SYMBOLS FOR MEANINGFUL COMMUNICATION
- A SYSTEM OF STANDARDIZED SIGNALS FOR MECHANICALLY CONVEYING INFORMATION BETWEEN POINTS SEPARATED BY A FINITE DISTANCE

Readers would be familiar with the Morse code system, which employs three elements or "symbols" (dots, dashes and pauses) to convey messages by either electronic means or light signals. The code requires that the sender and the receiver understand the meaning of each of the possible combinations of the three elements, and for both the sender and receiver to share a common language. A particular combination of the elements always has the same unambiguous meaning. There are many combinations used, one for every letter of the alphabet and for every numeral from zero to nine: a total of thirty-six combinations. Just like the letters and and numbers of the language, the code cannot convey meaning until the components are compiled into a language. So here then is what at first seems a "simple" code, but which in reality is a complex entity that can only contribute to meaningful communication in the context of a language.

With "colour coding", the "symbol" is light, either emitted or reflected, with meaning attributed to the colour (i.e. wavelength) property of the light.[5]

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[4] Macdonald, W.A. and Cole, B.L. (1988) Evaluating the role of colour in a flight information cockpit display. *Ergonomics*, 31, 13-37.

[5] It is technically extremely difficult to create light displays that are iso-luminous, in which the only variable is wavelength. Wavelength variations in practical displays are always accompanied by changes in brightness or luminance.

The simplest of colour codes, which I label **CC1**, consists of a single display element such as a single light that changes colour when the meaning is changed. A CC1 type code is employed in the battery charger for my cellular telephone. A small, single LED mounted on the charger has three possible displays:

1. Off: charger inoperative.
2. On and Red: battery charging;
3. On and Green: battery is charged.

This device uses colour to provide essential information if use of the cellular telephone is to be reliable. The meanings are unambiguous. A simple code for a simple task demanding simple recognition and response. Or is it? The single light does not exist in isolation. It is mounted on a structure, made of black plastic, which was supplied at the time of purchase of the cellular telephone. After the purchase, the handbook was studied and the item was identified as a battery charger for a very specific appliance. In other words, the meaning of the simplest of colour code examples is non-existent without an appreciation of the context in which the code is used. And what of the response? Understanding the code within its context is then followed by appropriate action. "If the light is red, wait until it turns green and then remove the battery from the charger and replace it in the telephone" could exemplify appropriate behaviour in response to this code.

The point to be made is that in this instance of the simplest possible of colour coding examples, it is the response that is of the utmost importance, not the recognition of a colour, although the two are clearly related in CC1 colour usage.

The second type of "colour coding", which I shall label **CC2**, uses a different mechanism. Here the colour of the light is fixed and meaning is conveyed by the light being either on or off. There are many examples available from everyday objects: lights on electric kettles, television and radio sets, dashboard lights of many descriptions in motor vehicles and so on. In this the choice of colour may be determined by some convention (for example that red means danger and green safety) but the essential information is conveyed by the on or off status of the light itself.

Road traffic signals are a complex example of CC2 coding. Consider the many elements that make up even the simplest of road traffic signal arrays. As in the example given for CC1 type coding, a lengthy discussion could be gone into on the questions of context and appropriate response. Indeed, such a discussion could be the subject of an entire paper in itself. Such arrays are typically mounted on distinctive backgrounds, on equally distinctive support structures, and in defined geometric patterns. In addition there are multiple other components such as "walk" and "don't walk" signs and a host of various arrows for "turn", "don't turn" and so on. Suffice it to say that the colours employed in traffic signal systems have no meaning unless the context is first understood and consideration is given to the many other factors that determine what an appropriate response might be to a given display. It is the totality of the structure, the perception of which defines for the observer that the light he is seeing is indeed a traffic signal light. If a person from a culture where road traffic signals didn't exist were to be given instructions to "Go when you see a GREEN light, Stop when you see a RED light and Be Careful when you see an AMBER light" the result would predictably be chaotic.

Thirdly, in what I shall label **CC3**, colour is used to delineate and differentiate between elements of a display. This usage of colour may be seen in maps, circuit diagrams and plans. There is no specific connotation embodied in the choice of colour, and this usage typically involves a larger number of colours than is used in examples of CC2 type codes. And here, once again, the question needs to be considered as to what is the context of the display, and what action or understanding is required from the user in interpreting the information.

The Pilot.

Since this paper is confined to considering the question of the Aviation Colour Perception Standard, it is necessary to examine what it is that is expected of pilots. Only once this has been discussed, can we progress to consideration of the role of colour coding within any meaningful context. What do pilots do and how do they do it?

Pilots fly aeroplanes. By definition, these machines operate in a three-dimensional environment, unlike motor vehicles or ships that are restricted to a navigating on two-dimensional surfaces. In acquiring the skills needed, pilots study and learn much more than mere manipulative skills. The learning and training equip the pilot to understand and deal with a wide variety of normal and unusual flight conditions. At the end of the training, the pilot will be assessed by other pilots of equal or greater experience and skill, and will be judged as fit (hopefully) to hold a licence. The process relies entirely on the demonstration of necessary ability and knowledge.

In a typical flight, the pilot will begin with a deal of time in planning the flight, equipped with weather and other briefing materials. Charts will be studied, the route chosen, the fuel requirements calculated and the departure and destination airport layouts examined. During the various phases (take-off, climb, cruise, descent, approach and landing) the pilot will be busy monitoring aircraft systems, navigation equipment, weather, performance and will be on the lookout for unusual conditions. Except for controlled contact with the ground before takeoff and after landing, the greatest demand is that no accidental contact be made with any solid object outside of the pilot's aircraft.

The pilot's job is indeed a highly complex one, involving extremes of perception and manipulative skills. It is within this framework that the role of colour coding must be measured, and conversely the effective handicap of defective colour vision determined. This is so fundamental a point that I shall risk laboring the point again. <u>It is simply invalid under any notion of what does and what doesn't constitute genuine "scientific study" to measure the consequence of defective colour vision in the work that pilots perform by using experimental settings that are unrelated to the work-place of the pilot and using subjects that are ignorant of what pilots do.</u>

The AAT, in coming to the conclusions that it did, relied extensively on the testimony of practical and experienced pilots. It rejected contrived and irrelevant "experiments" that amounted to de-facto colour vision testing, and that had no regard for the complex environment, the high level of knowledge and cognitive skills that are inherent in the occupation of an aircraft pilot.

Defective Colour Vision

"Normal" colour vision relies on the unimpaired function of three distinct cone pigments (hence the term "trichromatic"). Like the cones themselves, the pigments occur in greatest abundance in the area of fovea. The plot of the sensitivity of each pigment to various wavelengths of visible light forms a typical bell shaped curve. One has its peak in the red zone of the spectrum, the

next in the green and the third peaks in the blue. There is extensive overlap of the three resulting sensitivity plots. Genetic coding for the "red" and the "green" sensitive pigments resides on the X-chromosome (and is therefore sex-linked), whilst that for the "blue" sensitive pigment resides on an autosomal (i.e. non sex-linked) chromosome.

Abnormal colour vision occurs when there is a reduction in function of one or other of these three pigments. When the red pigment function is reduced, the individual is classed as "<u>Protan</u>" (derived from the Greek root *PROTOS,* meaning "first"). If the degree of dysfunction is less than total, the sufferer is said to be "protanomalous". When total dysfunction is present, the individual is classed as "protanope". They are not separate conditions, but variations of degree of the dysfunction.

Dysfunction of the green pigment puts the individual into the "Deutan" group (derived from the Greek word for "second"). In the same manner as above, deutans can be subdivided according to the severity of the dysfunction into deuteranomal and deuteranope subgroups, where the latter demonstrate complete green receptor dysfunction. Exactly the same applies to the blue pigment resulting in the terms tritanomal and tritanope.

The sex linked (i.e. red and green dysfunctions) occur in approximately 8 to 10 percent of the male population. The incidence in females is between 0.6 and 1 percent[6].

The Colour-defective

Dr. Clark's opening paragraph in his article states:
"Practical interest in the topic arises from the fact that some individuals who may otherwise be excellent candidates for a professional flying career find themselves at risk of exclusion because their perception of colours is reliably different from that of most of the population, i.e. their vision is colour-deficient. They may believe that they can see very well indeed, and tend to become vocal about rejection at their selection stage. The test methods and standards are often queried, and appeals are made on the basis of unfair and unnecessary discrimination".

What Dr. Clark is too polite to say is that colour-defective people often deny they are colour-defective. I was one such person early in the piece. But denial is not the issue (see below). There are many instances known to me where the very first time a candidate learned of being colour-defective was at an aviation medical examination. The point lost on Dr. Clark is that the denial was based on having lived and navigated through life successfully in blissful ignorance of the "importance" of colour coding. We now have a significant population of colour-defective pilots who can add successful aviation careers to the list of life's achievements. One could argue from first principles for the paramount importance of binocular vision in depth perception, denying all the while the accuracy and skill of the falcon or kingfisher in capturing its prey.

One of the reasons colour-defectives have had such a difficult time historically in aviation is that they typically suffer a delusion with respect to their colour vision. Prior to my own case in the AAT in 1987, there were others that had failed. With hindsight, the reason is plain. In each instance the basis of the appeal by the colour-defective applicant was that he really wasn't so terribly colour-defective as was being made out. In his experience, derived from years of road traffic experience and from multiple other life experiences where "colour coding" was considered to be crucial, the colour-defective felt entirely confident that he could indeed "see" the colours, and in turn respond appropriately as the situation demanded. From the outset, such argument could be easily countered by bringing Ishihara plates or a Farnsworth Lantern into the courtroom and demonstrating to the assembled Tribunal members or judges that the applicant was indeed wavelength crippled.

Add to that the "scientific evidence" so typified by Dr. Clark's paper, and the outcome was a foregone conclusion. In each and every instance prior to 1987, the applicants received no more than a vote of sympathy for their efforts. The fundamentals were never even considered.

There is no data that establishes a causal relationship between colour-defective conditions and increased accident experience. This applies to both road and aviation studies.

[6] As an aside, I have one family in my practice where the father is a deuteranope, the mother is a protanope and they have three daughters who each have normal colour vision. If you can plot the genes in this combination, you have come a long way towards understanding the genetics of abnormal colour vision. If they had a son, could he possibly have been "colour normal"?

I can, and have often done so, take any colour normal observer for a drive through the most complex traffic situations and demonstrate without error that I know exactly when the traffic light is "green", "red" or "amber". The demonstration can include lights at great distances (well beyond the distance where any practical relevance begins), and include the many adjunctive components (pedestrian instructions, turn and no turn, give way and the rest). My driving behaviour would be indistinguishable from that of any colour normal[7].

Yet if the three colours of the traffic signal system were to be reduced to pin point sources, and presented in a "lantern test", I am equally confident I would make significant errors in naming the colours correctly. **Therein lies the paradox.**

If colour-defectives can pass road driving tests and pilot licence tests, and their behaviour is appropriate in terms of compliance with the rules and fulfilment of all the practical requirements, then the theoretical paradigm that underpins the colour perception standard must be questioned.

Yet, the fact is that colour-defectives are wavelength cripples from the moment of birth. They can never experience "colour" as a colour normal would. They confuse colours that are distinctly different to the colour normal. Their "colour vocabulary" is small compared to that of the colour normal. Indeed, colour normals generally find it fascinating to observe a colour-defective stumble and hesitate over the naming of a colour that to them is such a simple matter. There is no doubt that colour normals (and indeed Tribunals) regard colour-defectives with some degree of mistrust. After all, what does one think of a person who can swear that he "sees the colours" when simple demonstrations time and again prove the opposite? I am in frequent contact with a large number of colour-defectives, and I hear the claim by colour-defectives repeated over and over that "I can see the colours". My first advice to a new colour-defective contact is to cease the denial process. Then and only then can the relevance with respect to careers be confronted.

It isn't difficult to see how the mistaken belief in being able to "see the colours" might arise. Again, using road traffic signals as the example, colour-defectives see differences in the typical three basic lights and respond, as they are required to do. It is problematic whether the primary "cue" is wavelength, luminance or position. What matters is that they understand the intent of the signal, which they do and do consistently. Just like their colour normal counterparts, they make the assumption that it is the "colour" that conveys the meaning of the signal, and have no regard at a conscious level for the vast amount of other information that is available and indeed crucial to the outcome of the appropriate response. Intuitively, this leads the colour-defective to believe that he can "see the colours". But if the light of the same wavelength is displayed in a way that is devoid of context, such as is the case in lantern tests, time and time again the colour-defective will make errors in correctly naming the colours.

Lantern tests generally prove the existence of colour-defective vision. That is what they are designed to do and they do it well. The many other tests referred to By Dr. Clark confirm and quantify the extent of the defect. Many papers have been written about the merits of one lantern over another. For instance, in cases prior to the Pape and Denison AAT appeals, much reliance was placed on the fact that the Farnsworth Lantern was not truly representative of "aviation"

[7] My apologies for the extensive use of the "first person" throughout this paper. Being a deuteranope, a pilot and a medical practitioner, and having devoted great time and effort in coming to understand this complex topic, much of the insight has come from personal experience. That is in itself not an impediment to forming a logical and integrated approach to the subject matter. I do, however, recognize the risks inherent in such personal material.

coloured lights. It had been designed for testing prospective submariners, not pilots. This gave candidates some glimmer of hope that they might obtain relief. But it inevitably proved to be irrelevant to the main issue.

What distinguished my case and the Denison case from its predecessors was that we pleaded "guilty" to being colour-defective and then fought the case on the basis the **irrelevance of defective colour vision to the things a pilot does.**

It is well beyond the scope of this paper to examine each and every instance provided by Dr. Clark in his long list above. Again, the AAT did just that in a most comprehensive way. However, the reader can go through the list and, for each example, determine what type (CC1, CC2 or CC3) of usage of colour is involved. I shall give a few short examples:

- As stated above, one of the tasks of utmost priority confronting a pilot is that, apart from controlled contact before take-off and after landing, the pilot should avoid hitting other objects. At night significant fixed objects are marked with obstruction lights (which Dr. Clark points out are "usually red"). The fact is that elevated objects are so marked only near cities, towns and airports, which means they are usually seen against a host of other lights. Among those other lights there may well be other red light sources, as well as white (or other colour) lights that indeed occur on elevated objects (such as lights on tall buildings and bridges). The use of "red" lighting to mark significant elevated obstructions might be viewed as an example of CC3. However, what the pilot needs to know in order to avoid collision with the structure is essentially the relationship of the position of the structure to the projected flight path of the aircraft in a three dimensional sense. Categorically, wavelength coding cannot provide this information.

- Red lights are indeed ubiquitous in the aviation (external) environment, as listed by Dr. Clark. It is necessary to distinguish the nature of the source of the red light from whatever cues are available. Take for example the sighting of a red light on a dark night. It is not the wavelength information that tells the pilot that the source is an obstruction light, because exactly the same wavelength "information" is contained in the red navigation light on another aircraft and in the multitude of other "ubiquitous" red lights. In most instances such lights are simply ignored because they are instantly perceived as irrelevant to the flight. It is the perception of motion parallax that determines the significance of any light to the progress of the flight.

- Recognition of the presence of other aircraft is achieved by bright flashing strobes, of which the flash pattern is distinctive and unique to aircraft traffic. The colour of such strobes is entirely superfluous.

- The use of CC1 type colour coding is thankfully extremely uncommon in aircraft instrumentation. I have seen only one inconsequential example of it, but of course there may well be others. The example known to me is on the EFIS display of the B767, where the ADF frequency, which is primarily a numeric display (e.g. "260") changes colour when the particular ground station comes into range. It is a superfluous usage, again, because other indicators exist that provide the same information. For the rest, panel status lights employ the CC2 type of colour usage. Examples are the "three greens" of the landing gear lights. The colour is entirely superfluous. What matters is whether the lights illuminate when the gear is extended. Another example is the array of annunciator lights that illuminate when a malfunction occurs in one or other system. Keeping in mind that it is the pilot's response to a malfunction that is the ultimate concern, not the correct naming of a colour, in this usage of colour there can be no action taken until the nature of the malfunction is ascertained. This is in turn derived by reading and understanding the message that accompanies the illumination of the particular light. Unlike in popular conceptions and in the model used by so many colour vision standard proponents, the pilot's response to malfunctions of any nature requires systematic and thorough assessment and confirmation before corrective action is undertaken. The colours of such lights are irrelevant.

- The use of colour coding in the Visual Approach Slope Indicating Systems (VASIS) represents one of the few areas where concern about the ability of colour-defectives may be supported by logic. It also represents poor engineering design. On this one point Dr. Clark and I are in absolute agreement[8]. Of particular concern is the PAPI (Precision Approach Path Indicator), which utilizes red and white lights in a special way to indicate the position of an aircraft relative to a defined glideslope angle. It is an example of CC1 colour usage. The dangers inherent in the use of colour in VASIS systems goes beyond considerations of colour-defective users and apply significantly to colour normals. That aside, the point to be made is that it is an aid only and not essential to the achievement of a safe landing. Indeed, of the hundreds of airports in Australia, less than ten are equipped with PAPI systems. A far larger number are equipped with T-VASIS, an Australian invention that uses geometric rather than colour coding to provide glideslope guidance. Pilots speak very highly of T-VASIS and much less so of PAPI. Dr. Clark is on record[9] as strongly favouring the use of geometric as opposed to colour coding for reasons of safety.

CONCLUSIONS

1. Colour is present in aviation, certainly, but its use as a "coding system" is unstructured and haphazard. In all except a small number of instances, does "true" colour coding occur in aviation. In no instance can the use of colour coding be demonstrated to be necessary for the pilot to perform the duties required of him.

2. The scientific study of perception embraces several disciplines, which until the AAT cases referred to above, were not invited to contribute to the debate of the ACPS. Yet it is the study of perception, as opposed to that of vision, that lends scientific validity to the case against the ACPS. It is how the world is perceived that matters in determining what actions might follow.

3. Colour-defectives are "wavelength cripples", who by definition are less able than colour normals to distinguish between certain colours and to correctly name many colours. There is no association between colour-defective vision and conditions that retard learning or result in decreased motor skills.

4. There are now, particularly in Australia, significant numbers of experienced colour-defective pilots, whose operational performance by any measurement is equal to that of colour normals.

5. There is no data that links colour-defectiveness with increased risk of accident or incident.

6. So-called "scientific evidence" called upon to support the Aviation Colour Perception Standard is deficient. This is so because the theoretical paradigm used is in all instances distant and divorced from the operational realities.

7. PAPI (and other colour-based VASIS systems) are the only significant example in the aviation environment of "true" colour coding, where colour-defectives might be at a degree of disadvantage. However, systems such as PAPI are not essential to proper operations. There

[8] Clark, B.A.J. and Gordon, J.E. "Hazards of Colour Coding in Visual Approach Slope Indicators". Department of Defence, Aeronautical Research Laboratories. December, 1981.
[9] Ibid.

are simple engineering solutions available to remedy the disadvantages of colour coding in VASIS systems which would benefit colour-defectives and colour normals alike.

SUBMISSION.

1. There has appeared a window of opportunity to address the relevance of the Aviation Colour Perception Standard both nationally and internationally.

2. The scientific basis for the standard was seriously placed in doubt as a result of major reviews of all the evidence conducted by the AAT in 1987 and 1989.

3. No new evidence has emerged that supports any proposition that the Aviation Colour Perception Standard contributes in any manner to the safety of air navigation.

4. Use should be made of the substantial population of qualified, colour-defective pilots in this country to illustrate to the international aviation community the lack of logical basis embodied in this Standard.

5. The injustice done to individuals by application of a standard that has no scientific basis will not be tolerated and will be comprehensively challenged in the courts.

6. The Aviation Colour Perception Standard should be removed from the Regulations.

7. Sound engineering design standards must be sought and applied to aviation systems, aimed at avoiding the emergence of features that might disadvantage particular groups of users, such as, but not only, colour-defective users.

Many thanks to Dr Pape for this comprehensive and challenging article. Let the correspondence begin!

Two points to note - firstly, we are fortunate in having as Lane Lecturer at both of the upcoming conferences in Maroochydore and Taupo, Doug Ivan, Chief of Ophthalmology at USAFSAM Aeromedical Consultancy Service. Doug will be discussing the issue of colour vision in aviation, and has been sent a copy of this article and Dr Clark's.

Concerning the reference list for Dr Clark's article (see page 26), it was an editorial decision not to include this, rather than Dr Clark's. AvMedia does not purport to be a peer review medical journal, and this decision was made in the interests of economy, given that the general readership's requirement to access the reference list would be limited.

David Powell