COLOUR PERCEPTION STANDARDS IN AVIATION: SOME IMPLICATIONS OF THE AAT DECISIONS REGARDING COLOUR PERCEPTION AND AVIATION

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ABSTRACT

The International Civil Aviation Organisation (ICAO) colour perception standard may be analysed as a form of argument; that is, it may be considered as a conclusion drawn logically from three assumptions. These assumptions are (i) that colour is used extensively as a feature of information-presentation systems in aviation; (ii) that normal colour vision is *necessary* for safe information processing from such systems, and consequently, safe performance of the duties of aviation, and (iii) that defective colour vision results in unsafe information processing from such displays, and consequently, unsafe performance of duties in aviation. For the application of the ICAO colour perception standard to be evidenced-based, the truth or falsity of each of these assumptions needs to be evaluated using appropriate empirical tests. An informal demonstration of an empirical test of the second assumption is presented showing that the presence of colour is neither *sufficient* nor *necessary* for appropriate information processing from one information-presentation system. The limitations of the kind of evidence provided by the demonstration are noted, and a proposal for the collection of more appropriate empirical evidence is proposed. This proposal is possible because of two landmark decisions made some 20 years ago by the Administrative Appeals Tribunal (AAT) in Melbourne, Australia, in relation to the aviation colour perception standard. Because of these decisions, pilots with defective colour perception were able to gain extensive flying experience commanding modern, sophisticated aircraft. That is, a group of pilots with defective colour perception now exists having similar flying experience to the flying experience of pilots with normal colour perception. These two groups of pilots provide a pool of possible participants for a more-appropriate empirical test of the assumption underlying the colour perception standard than had been possible before the AAT decisions. A proposal for such an empirical test is outlined.

WHAT IS ASSUMED IN PROPOSING AN AVIATION COLOUR PERCEPTION STANDARD?

The International Civil Aviation Organisation (ICAO) colour perception standard for those wishing to apply for a pilot's licence is set out in the July 2001 Annex 1 to the Convention on International Civil Aviation[1], and reads in part:

> "The applicant shall be required to demonstrate the ability to perceive readily those colours the perception of which is necessary for the safe performance of duties."

The ICAO colour perception standard can be analysed formally as a form of logical argument. In common language, the word 'argument' refers to a situation where there is some opposition or contradiction in two or more points of view. However, in more formal logical analysis, the word 'argument' refers to a situation where a conclusion is drawn from one or more assumptions or premises. Analysed formally as an argument, the ICAO colour standard is based on three assumptions, as follows:

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> *Assumption 1:* There is extensive use of colour-coded information in the aviation environment.
>
> *Assumption 2:* The "safe performance of duties" in the aviation environment requires "the ability to perceive readily those colours the perception of which is necessary for the safe performance of duties."
>
> *Assumption 3:* Without "the ability to perceive readily those colours the perception of which is necessary for the safe performance of duties", these duties will be performed unsafely.

The value of undertaking such a formal logical analysis of the ICAO colour perception standard is that the analysis makes the assumptions underpinning the colour standard explicit, and thereby allows the truth or falsity of the assumptions to be tested. Such tests of the truth or falsity of the assumptions are needed to determine whether the argument based on these assumptions, in this case, the colour perception standard, is true or false. That is, such evaluations of the three assumptions provide an appropriate evidence basis for the colour perception standard.

Let us consider in turn each of the three assumptions identified above. There can be little doubt that there is extensive use of colour in systems used to present information in the aviation environment. This use of colour occurs inside modern aircraft where, for example, there is extensive use of coloured displays to present information to pilots. The use of colour also occurs in the aviation environment external to the aircraft, where, for example, there is extensive use of colour in runway and taxiway lighting at airports, and in devices such as PAPI used to help pilots maintain correct glide slope while on approach to landing. Figure 1 shows examples of this use of colour both inside the cockpit of a modern aircraft, and in the environment external to aircraft. More formal support for the truth of this assumption is provided by recent analyses of the aviation environment by Barbur, Rodriquez-Carmona, Evans, and Milburn (2009a, b)[2] in which they attempted to provide a classification of the role played by colour in this environment.

Figure 1. The left panel shows the Pilot Flying Display (PFD) of the Airbus A330. (With permission, QANTAS Training Material)
The right panel shows a typical runway lighting system with approach lighting. (www.intertecnica.de)

While there is little doubt about the truth of the first of the three assumptions identified above, the same cannot be said about the second and third assumptions. The second assumption underpinning the colour perception standard is that the "safe performance of duties" in the aviation environment requires "the ability to perceive readily those colours the perception of which is necessary for the safe performance of duties." The use of the word "necessary" makes a strong claim about the role of colour in processing information in the aviation environment. This strong claim is that the use of

colours in information displays, and the ability of pilots to "perceive readily" (to quote the ICAO statement) these colours, is a prerequisite or requirement for appropriate information processing, and therefore safe "performance of duties". The second assumption, and its strong claim, is problematic. The truth or falsity of this second assumption is an empirical matter, and the kind of empirical evidence used to support the truth of the second assumption has been questioned in the course of the Administrative Appeals Tribunal (AAT) considerations of the colour perception standard in aviation. The basis of this questioning is discussed in more detail below.

The third assumption underpinning the ICAO colour perception standard is that without "the ability to perceive readily those colours the perception of which is necessary for the safe performance of duties", these duties will be performed unsafely. Implicit in this third assumption is the 'fact' that there are individuals who do not "perceive [colours] readily". It is more than 200 years since the publication of the first scientific paper on defective colour vision by the English chemist John Dalton (see Dalton, 1798)[3], in which he described his own misperceptions of colour. Since then, scientific knowledge of human colour perception, both normal and defective, has increased greatly. The procedures available to measure colour perception have also improved, becoming more sophisticated, and enabling more detailed specification of the nature of defective colour perception. In summary, there is little if any doubt defective colour perception is a condition that is readily demonstrated and measured, and is well understood. However, the fact of the occurrence of defective colour perception has no implication about the truth or falsity of the assumption that those with defective colour perception will perform duties in the aviation environment in an unsafe manner. As was the case with the second assumption, the truth or falsity of the third assumption is an empirical question. Furthermore, as was the case with the second assumption, the kind of empirical evidence used to support the truth of the third assumption has been questioned. Before outlining the problems identified during AAT consideration of the colour perception standard in aviation, some discussion of the role of colour in information-presentation systems is warranted.

IS COLOUR SUFFICIENT OR NECESSARY FOR APPROPRIATE INFORMATION PROCESSING OF DISPLAYS IN THE AVIATION ENVIRONMENT?

The mere use of colour in the aviation environment exemplified in Figure 1 has no implications for the truth or falsity of the second and third assumptions identified above. For example, if this use of colour is only for aesthetic reasons, then the question of the role of colour as an information code does not arise; colour is for 'looks', not for 'information'. However, if colour is present to serve a functional role, not merely an aesthetic role, this raises the question of the nature of the functional role of colour as an information code. Typically in cockpit displays of the type shown in Figure 1, colour is one of several visual information codes (e.g., a verbal code, a spatial code, an achromatic luminance/brightness code) used simultaneously. In such displays, the question of the role of colour as an information code, which is at the heart of the second and third assumptions, becomes a more-complex question. Despite this complexity, the empirical test that is proposed later in the paper will allow appropriate evaluation of the interactions between colour and the other visual information codes present in multi-coded information displays.

Before discussing the proposed empirical test of the second and third assumptions, we present an informal demonstration involving the Electronic Central Aircraft Management (ECAM) display in an Airbus A330 aircraft shown in Figure 2. As its name suggests, the ECAM display is designed to provide Airbus A330 pilots with information "necessary for the safe performance of their duties" in relation to emergencies that may arise in a flight. During an emergency, the display presents automatically, on a need-to-know basis, information about the emergency, the diagnosis of the problem, and the actions that crew need to undertake to deal with the problem. As is clear from Figure 2, colour is used extensively in the ECAM display, and is used, in part, as follows:

White colour : Used to show titles on the ECAM display.
Green colour: Used to show normal conditions.
Amber colour: Used to show abnormal conditions requiring some attention, but no immediate action.
Red colour: Used to show abnormal conditions of a serious nature and requiring immediate action.
Blue colour: Used to show actions to be undertaken by aircraft crew.

Figure 2. The ECAM display from an Airbus A330 aircraft showing the extensive use of colour in the display. (With permission, QANTAS Training Material)

The question of interest is whether the colours used in the presentation of these different types of information in the ECAM display are required for the information to be processed correctly.

There are two ways of considering this question of interest. The first is to ask whether colour alone is *sufficient* for the information presented in a coloured display to be processed correctly. Put simply, is it the case that seeing the colour is enough to see the information? The second way of considering this question of interest is to ask whether colour is *necessary* for the information presented in a coloured display to be processed. Put simply, is it the case that not seeing the colour means that the information is not seen?

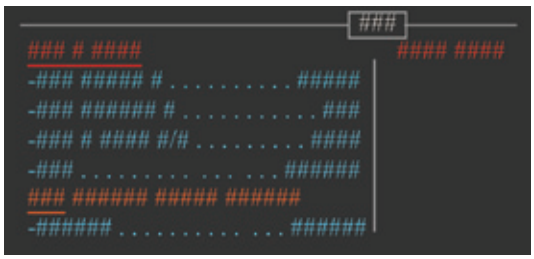

Figure 3. A version of the lower section of the ECAM display from an Airbus A330 aircraft with the colour retained, but text replaced by # marks. (Devised by Author 2)

Figure 3 shows a version of the lower section of the ECAM display shown in Figure 2 in which the colours used in the original display have been retained, but the text has been replaced by # marks. Inspection of Figure 3 shows that the presence of colour alone is not *sufficient* for meaningful information to be processed. Without the text, the series of coloured hash marks is meaningless. Figure 4 shows a different version of the lower section of the ECAM display

shown in Figure 2 in which the colours used in the original display have been removed, but the text has been retained. Inspection of Figure 4 shows that the presence of colour is not *necessary* for meaningful information to be processed. The colourless display in Figure 4 clearly shows that the emergency is a fire in engine number 1, and shows also the actions to be undertaken by the crew.

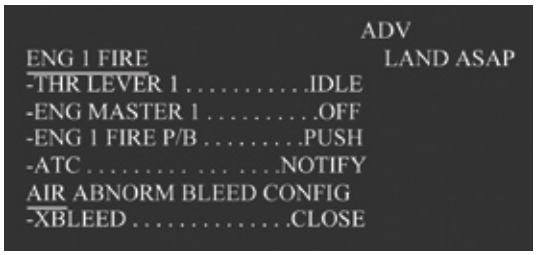

Figure 4. A version of the lower section of the ECAM display from an Airbus A330 aircraft with the text retained, but the colours removed. (Devised by Author 2)

Taken together, Figures 3 and 4 are compelling demonstrations that colour is neither *sufficient* nor *necessary* for meaningful information to be processed from the Airbus A330 ECAM display. Despite the compelling nature of this informal demonstration, we stress that the 'evidence' it provides is not an appropriate basis for the evaluation of the second assumption underpinning the colour perception standard. Before discussing more appropriate evidence, we want to point out that the Airbus is equipped with an array of devices designed to draw the crew's attention to the ECAM display. For example, during a condition requiring attention but no immediate action (i.e., a caution condition), a loud single auditory signal is presented, as is a visual display, separated from the ECAM, consisting of the words 'MASTER CAUTION' in black text on an amber background light. During a serious condition requiring some immediate action, a loud continuous auditory signal is presented, as is a different visual display, separated from the ECAM, consisting of the words 'MASTER WARNING' in black text on a red background. In summary, in an actual situation of serious equipment malfunction or of imminent danger (e.g., impending stall or dangerous proximity to terrain) information is presented to the crew using multiple sensory modalities, and from spatially-separated sources.

What are the implications of multiple sources of information of the type described in the previous paragraph? Whether individuals in the aviation environment are presented with a single source of information, or with multiple sources of information, the question of whether they make proper use of such information so that they engage in "safe performance of duties" is an empirical question; that is a question that must be answered using appropriate evidence. This is the case whether these individuals have normal colour perception or defective colour perception. But what is the most appropriate evidence that should be collected to answer the question, and how should this evidence be collected? These issues are discussed in the remainder of the paper.

AAT DECISIONS IN RELATION TO THE AVIATION COLOUR PERCEPTION STANDARD

The informal demonstration in Figures 3 and 4 that colour is neither sufficient nor necessary for appropriate information to be processed from the Airbus A330 ECAM does not provide the kind of evidence allowing proper assessment of the ICAO colour perception standard. Before outlining what such evidence should be, ideally, it is necessary to discuss a more formal and rigorous examination of the ICAO colour perception standard that was carried out by the AAT in Melbourne, Australia some 20 years ago in relation to two separate cases. It is because of the AAT decisions in relation to these cases that more-appropriate evidence, which was not possible to gather at the time of the hearings, can now, in theory at least, be gathered. The two cases were: Re: ARTHUR MARINUS PAPE And: SECRETARY, DEPARTMENT OF AVIATION (DOA)[4] and, Re: HUGH JONATHAN DENISON And: CIVIL AVIATION AUTHORITY (CAA)[5].

Before commenting specifically on each of the cases, it is instructive to make two general comments about the AAT appeals overall:

The first comment is to do with the scope and thoroughness of the AAT process. The two cases, taken together, took up more than 38 days of hearings. Some 25 witnesses were called to give evidence, including airline pilots, air traffic controllers, and expert witnesses from the fields of aviation medicine, optometry, and psychology. In summary, the AAT hearings represented a wide-ranging and thorough consideration of the evidence of relevance to the question of whether there should be a colour perception standard in aviation.

The second comment is to do with two aspects of the evidence provided by the appellants that, on the basis of the AAT's report, seemed to influence its decisions.

(i) The first aspect was the critique of the nature of the empirical evidence used by the Department of Aviation (DOA) and the Civil Aviation Authority (CAA) to support the application of a colour perception standard (e.g., Cole & MacDonald, 1988[6]; MacDonald & Cole, 1988[7]). The essence of this critique was that the empirical evidence had very little to do with measuring the safe performance of the duties involved in flying aircraft, and a lot to do with measuring colour perception performance. Put simply, the empirical evidence put forward to support the application of a colour perception standard in aviation was basically empirical evidence for defective colour perception, and not empirical evidence for defective, or unsafe, aviation. Although the empirical evidence involved many experiments and many different experimental conditions, these experimental conditions could generally be characterised as variations of standard tests of colour perception. And since the participants in this empirical research had all been screened into 'normal' and 'defective' groups on the basis of their performance on tests of colour perception, it was inevitable that the participants so grouped would perform differently on the alternative versions of colour vision tests that formed the experimental conditions.

(ii) The second aspect was to do with the theoretical approach that underpinned the empirical research used to support the application of a colour perception standard in aviation. This theoretical approach assumed that the information provided to humans by their senses was impoverished and ambiguous. Additional processing was needed before accurate information about the world could be perceived. An alternative theoretical approach to perceptual-motor tasks like flying a plane has been proposed, and was described to the AAT. This alternative approach was set out by James Gibson[8] in his 1979 monograph, *The ecological approach to visual perception*. This alternative approach places more emphasis on the richness of the environmental information available to those engaged in tasks like flying a plane.

The first case to be discussed is Pape and the DOA. This case was significant because it was the first time an aviation colour vision standard had been successfully challenged anywhere in the world. The appellant, an author of this paper, a deuteranope, and the holder of a commercial pilot licence and command instrument rating, sought to have removed the limitation placed on his private pilot licence by the DOA that precluded him from piloting aircraft at night. The AAT upheld the appeal, and ruled that the appellant be permitted to exercise the private licence at night with certain extra conditions, namely the carriage of standby radio apparatus and an increase in IFR approach minima. These extra conditions were later removed in the decision given in the second appeal. The second case to be discussed, Denison and the CAA became, by mutual agreement between the parties, a consideration of wider scope than that of Pape and the DOA. It

involved a wide-ranging investigation of the aviation colour perception standard, and included all types of defective colour perception. The use of colour in larger commercial aircraft, including the use of Electronic Flight Instrumentation System (EFIS) cockpit display equipment was considered, as was the use of colour in the external aviation environment. It is a matter of record that at the close of the hearing phase of Denison and the CAA, all parties agreed that all the evidence available at that point in time had been subjected to exhaustive discussion and scrutiny. The decision of the AAT was to uphold Denison's appeal, and in setting out the bases of this decision, the AAT made clear its view that defective colour perception did not pose a significant threat to the safe performance of the duties involved in flying aircraft.

CONSEQUENCES OF THE AAT DECISIONS FOR AN APPROPRIATE EMPIRICAL TEST OF THE ASSUMPTIONS UNDERPINNING THE ICAO COLOUR PERCEPTION STANDARD

A consequence of the AAT decision in the case of Denison and the CAA was that pilots with defective colour perception were able to increase their flying experiences beyond the previously restricted range of such experiences imposed by the aviation colour vision standard. Indeed, pilots with defective colour vision were now able to embark on careers in aviation involving flying modern, large and sophisticated aircraft equivalent to the career paths available to pilots with normal colour perception. Table 1 summarises the flying experiences of two such pilots. Inspection of Table 1 shows that these two pilots have each more than 8000 hours flying experience in a range of sophisticated aircraft. Both have served in command of such aircraft. In addition to the information provided in Table 1 it is instructive to note that the regular flight simulator check and training reports that all pilots operating aircraft at this level of sophistication are required to undertake have been, for these pilots, completed at a very high standard. There have been no questions raised regarding the "safe performance of duties" of these pilots.

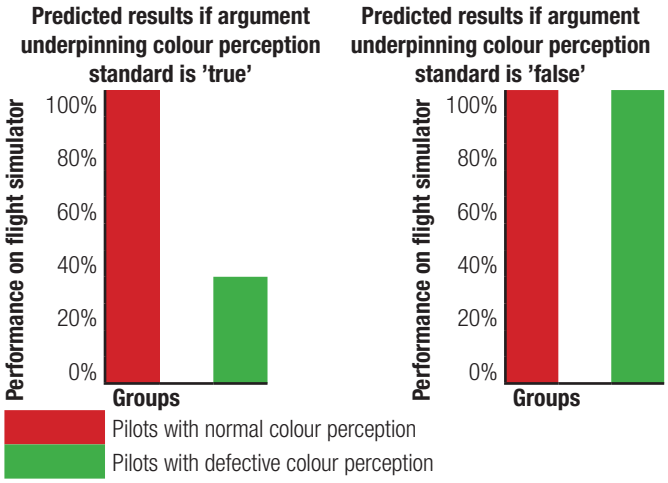

Figure 5. Predicted results of an ideal empirical test of the argument underpinning the colour perception standard. The panel on the left shows the predicted results on the flight simulator if the argument is 'true'; that is, pilots with defective colour perception will perform worse than will pilots with normal colour perception. The panel on the right shows the predicted results on the flight simulator if the argument is 'false'; that is, pilots with defective colour perception will perform the same as will pilots with normal colour perception.

A further consequence of the AAT decision is the possibility of the carrying out of empirical research that could provide evidence allowing more-appropriate evaluation of the need for the aviation colour perception standard than had been possible before the AAT decisions. Paradoxically, this includes the evaluation of the AAT itself. This statement should not be seen as a criticism of the AAT, nor of the evidence it considered. Rather, this statement reflects the limitations of the empirical evidence that was available before the AAT decision. This empirical evidence was problematic in two ways.

The first problem was that the evidence was not collected from participants who were pilots who differed only in their colour perception abilities. Instead the evidence was typically collected from participants who were not pilots and were selected to take part because they either had normal of defective colour perception.

The second problem was that the evidence was not based on measuring the quality of "performance of duties" involved in piloting aircraft. Instead, as noted earlier, the empirical evidence was based on comparison of performance on quasi-tests of colour perception.

The ideal empirical test of the assumptions underpinning the ICAO colour perception standard involves removal of both the problems identified above.

AN IDEAL EVALUATION OF THE ASSUMPTIONS UNDERPINNING THE ICAO COLOUR PERCEPTION STANDARD, AND POSSIBLE RESULTS OF SUCH AN EVALUATION

The ideal empirical evaluation of the assumptions underpinning the ICAO colour perception standard would firstly involve as participants samples of pilots who were representative of the population of pilots to which any empirical results could be properly generalised. These samples of pilots would be matched on some set of variables, but would differ in their colour perception abilities. This difference is the critical variable of interest. It is beyond the scope of this paper to provide details of the variables (e.g., health status, age, etc.) on which the samples of pilots in the proposed research would be matched, except to say that central to this list of matching variables must be the variable of amount and quality of flying experience. Until the AAT decisions, there was little if any opportunity for pilots with defective colour perception to progress in their aviation careers and flying experiences in ways that paralleled the career progress of pilots with normal colour perception. Pilots with defective colour perception were limited in the size and complexity of aircraft they could command, and the conditions under which such command could be exercised. However, with the growth of a cohort of pilots of which the two shown in Table 1 are examples, the possibility now exists for obtaining an appropriate sample of pilots with defective colour perception that match the range of flying experiences achieved by pilots with normal colour perception.

In addition to being based on participants that allow proper generalisation of results to the population of pilots, the ideal empirical evaluation of the assumptions underpinning the ICAO colour perception standard must be based on experimental tasks that allow proper generalisation of results to the "safe performance of duties" in aviation. Part of the critique of the empirical evidence used to support colour perception standards discussed earlier was that this evidence involved experimental tasks that had very little, if anything, to do with the actual task of piloting aircraft. The obvious reply to this critique would be to replace these artificial tasks with experimental conditions that involved the actual piloting of aircraft. Such a proposal is manifestly impractical and inappropriate on numerous grounds. Collecting data during the actual piloting of aircraft would not only be extremely expensive, it would involve exposure of participants to such danger that human research ethics committees would be loath to approve such data collection. What is needed is a task that approximates, as closely as possible, the "performance

of duties" actually involved in flying aircraft, and does so relatively inexpensively, and without danger to participants. Such a task is available, of course. It is the task of flying an aircraft simulator. This is considered to be so close to what is involved in actually flying aircraft that pilots who fly modern sophisticated aircraft such as the Airbus A330 are required to demonstrate their continuing proficiency and "safe performance of duties" in aviation by undergoing regular flight-simulator-based assessments. The ideal evaluation of the ICAO colour perception we propose would involve exposing appropriate samples of pilots to a range of experimental tests in a flight simulator. As we said earlier, it is beyond the scope of this paper to provide details of such flight simulator tests and the dependent variables that could be measured. However, we do point out that flight simulators are ideal tools for experimental data collection because flight simulators can be used to expose participants to identical experimental conditions. More importantly, these experimental conditions can involve unremarkable flying situations, and also emergencies of different types forcing participants to use all their abilities, including their colour perception abilities, for the "safe performance of duties".

The two panels of Figure 5 show the hypothetical and highly simplified results of the ideal evaluation of the assumptions underpinning the ICAO colour perception standard we propose. The results are highly simplified in that the range of possible measures of "safe performance of duties" in the flight simulator is collapsed into a single measure which we have termed 'Performance on flight simulator'. The panel on the left of Figure 5 shows the predicted results on the flight simulator task if the assumptions underpinning the ICAO colour perception standard are true. Participant pilots with defective colour perception will perform worse than will participant pilots with normal colour perception. The panel on the right of Figure 5 shows the predicted results on the flight simulator task if these assumptions are false. Participant pilots with defective colour perception will perform the same as will pilots with normal colour perception. The pattern of predicted results if the underpinning assumptions are true or false, that is, if the colour perception standard is relevant to "safe performance of duties" in aviation, are clearly different, enabling a clear evaluation of the need for such a standard.

Table 1. Summary of the flying experience of two pilots with defective colour perception who have been able to obtain this experience as an outcome of the AAT decisions relating to the aviation colour perception standard.

	Pilot 1	Pilot 2
Age:	42	32
Colour perception defect:	Protanope	Deuteranope
Total hours flown:	8500 hours	8800 hours
Flying experience (aircraft flown):	Airbus A320/321 Embraer 170 Dash 8 100/200/300 CASA-212 PA-31-350; PA-44 C404, 310/320 Aero Commander 500S Cresco 750 Beechcraft Duke	C310/320 Baron Travelair PA44; PA31 Metro 3/23 Saab 340 Boeing 737-300/800
Flying experience (recent flight crew status):	2005-2007 Command Embraer 170 2007-present First Officer Airbus A320 (preparing for command training)	2006-present Command Boeing 737-800

CONCLUDING COMMENTS

To make clear the assumptions that underpin the ICAO colour perception standard we set out an analysis of the standard as a logical argument, and identified three assumptions. We discussed problems with the empirical evidence used to support the application of the colour perception standard identified during the AAT consideration of the standard almost 20 years ago. Since these AAT decisions regarding the standard there has emerged a cohort of pilots with defective colour perception yet with extensive experience flying modern, large, and sophisticated aircraft. We argued that these pilots represent a potential pool of participants for a definitive test of the aviation colour vision standard. We proposed that such a definitive test should involve comparison of the "performance of duties" (to quote the ICAO colour standard) on an appropriate set of flight simulator tasks of two groups of pilots matched on all relevant variables, and differing on the variable of colour perception abilities. We appreciate that carrying out the evaluation we propose would be a complex and expensive undertaking. However, we feel that the effort is warranted because the results of the kind of evaluation we propose would provide the strongest possible basis for the need for and continued application of the colour perception standard, or its removal.

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