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HELICOPTER COCKPIT DESIGN FOR NIGHT GOGGLE COMPATIBILITY

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ABSTRACT

This paper examines the way in which night goggles are being used in United Kingdom military helicopters for low-altitude flying. The problems of instrument lighting, narrow depths of field inside the cockpit and reflections are described.

The particular problems inherent in the 'super-dim' lighting approach are explained by examining the different spectral responses of the human eye and image intensifiers and the behaviour of tungsten-filament bulbs operated at lower than standard voltages.

A fundamentally different method of cockpit lighting is described in which separate floodlights are used having no infra-red emission. Practical implementation of these principles is suggested and data on various sources of light are given.

Two improved instrument focussing systems are described which have considerable advantages. These are the complementary filter/shared aperture system developed and flight tested by the RAE and the complementary filter/see-through goggles system at present being investigated.

1 INTRODUCTION

In their military role, helicopters find much of their application in flying and manoeuvring very close to the ground. In a hostile environment, helicopters must fly close enough to the ground to make full use of ground contours, trees and buildings to avoid detection by the enemy. The extension of helicopter operations into night time requires the same kind of 'nap of the earth' flying but without using artificial illumination. Both by day and night, the pilot must have a very good view of the ground in his immediate vicinity as well as his flight instruments.

Whilst the use of unaided vision allows this type of flying to be extended into clear nights with strong moonlight, this condition is rare and any real advance into a 24 hour capability requires the use of image intensifiers to enhance the pilot's vision. Although thermal infra-red piloting aids (FLIR) are being developed, they will, for some years, be very heavy, complex and expensive and the alternative, comparatively cheap and simple image intensifier night vision goggles have already proved of great value. The long development time for practical FLIR piloting systems is such that night goggles must be considered as an important night vision aid for most helicopters for several years.

Piloting a helicopter very close to the ground while wearing night goggles is by no means as simple as it may seem. The main problems are the excessive brightness of cockpit illumination, the difficulty of focussing on instruments, controls and maps, the narrow field of view, poor resolution, monochrome image, reflections from windows and the weight of the goggles on the head.

This paper examines some of these problems, proposes short and medium-term solutions and presents two new designs of night goggles which help to reduce some of the problems.

2 PRESENT-DAY NIGHT GOGGLES

The Army Air Corps and RAF helicopters have been operated for a number of years with the US-manufactured AN/PVS-5A made by ITT and Litton Industries and the F4907 made by ITT which are equivalent. Approximately half the UK total are standard, manual-focus versions and half have image intensifier tubes with stepped fibre-optic input windows giving 'bifocal' focussing.

In the bifocal goggles, the bottom 40% of the field of view is therefore in focus for objects of typically instrument panel distance while the top 60% is focussed for far distant objects. The bifocal distance is 850 mm in earlier models and 700 mm in recently purchased equipment.

Provided that the pilot can place the bifocal segment image on the desired instruments and position his head to within about 35 mm of the nominal distance (850 or 700 mm), he can read those instruments. It is clear, though, that the 35 mm tolerance is far too small to encompass the possible range of eye to instrument distance even in one helicopter. When different types of helicopter, pilots' leg length and seating position are considered, it is found that even the bifocal focussing system leaves much to be desired[4,6,7].

3 PRESENT-DAY OPERATION OF GOGGLES IN THE COCKPIT

Flight instruments are illuminated either by pillar lights or internal lights. In both cases tungsten-filament bulbs are used. Instrument lighting, set to normal, naked eye, night flying brightness is far too bright for use with night goggles[4,6,7]. Reduction of lighting levels by the usual rheostat controls has several adverse effects when viewed through night goggles. A bank of instruments controlled by one rheostat will normally exhibit increasing uneveness of illumination at low levels, with some instruments still too bright while others become unreadably dim. The over-bright instruments are likely to reflect in the cockpit transparencies and mask the usually low-contrast outside-world image. Any over-bright instruments or other cockpit lights will also reduce the gain of the goggles (which must have automatic gain control for 'hands-off' operation) and further degrade the all-important outside-world image.

Finally, since even properly dimmed instrument lighting produces overloading in small areas of the image intensifier picture, the appearance of the instruments is excessively contrasting compared with the normal, naked-eye view.

Boeing-Vertol have produced a system for the CH47 Chinook helicopters for the RAF which, at considerable cost and weight, gives a balanced 'super-dim' lighting control for the entire cockpit including illuminated warning lights, buttons and panels.

With cockpit lighting set at this 'super-dim' night goggle level, none of the instruments can be seen by the naked eye. There is therefore a need to include a single, master switch which reverts all the lighting to a level suitable for naked-eye viewing.

Having set up the 'super-dim' lighting, any uncontrolled lights in the cockpit such as aircrew torches will cause severe problems for the pilot.

Present generation night goggles and standard maps do not allow the realistic, operational use of the goggles to read the maps. Map reading is therefore done by a second pilot with the naked eye using a shielded torch. The torch is then blanked or switched off while he uses the goggles, hand-held or hinged to his helmet, to look out of the window. This process is continuously repeated and obviously cannot be done by a first pilot who also has to fly the aircraft and spends 95% of his time looking outside.

4 SHORT-TERM IMPROVEMENTS TO COCKPIT LIGHTING

The AN/PVS-5A or similar goggles are likely to be used in UK military helicopters for a few years. The manual focus and bifocal varieties will be used together and third-generation image intensifiers should be in production within three or four years. It will then be possible to utilise the increased sensitivity of the latter to provide alternative and more satisfactory focussing systems which will be described later.

Most cockpit lighting is by tungsten-filament lamps and most flight instruments are illuminated by such lamps. The high sensitivity of image intensifiers results in their severe overloading when naked-eye-compatible lighting is used. Unfortunately, the simple expedient of reducing the voltage on the tungsten-filament lamps, while dimming them visually, appears to have little effect on the goggles until the lamps appear to be almost out. Fig 1 shows that the spectral sensitivity of the human eye and of present-day (second-generation) and future (third-generation) image intensifiers are very different. Fig 1 also shows the spectra of a 28 volt tungsten-filament lamp when operated at various reduced voltages. The curves have been scaled so that their values are equal to unity at 560 nm wavelength. It is seen that, at lower voltages (and filament temperatures) a higher proportion of the radiation is at near infra-red wavelengths, invisible to the human eye. The relatively high sensitivity of image intensifiers to this near infra-red accounts for the large discrepancy between naked eye and night goggle lighting when tungsten-filament lamps are used.

A typical naked-eye setting is 16 volts, at which the filament is at about 2100 K and a typical 'super-dim' setting for second-generation goggles is 6 volts (1400 K). At the latter setting it can be calculated that the lighting is about 1000 times too dim for the naked eye!

It can be seen from Fig 1 that the simple removal of the near-infra-red radiation beyond, say, 550 nm would barely affect the naked-eye brightness while considerably reducing the brightness seen by the goggles. The lamps could then be operated at much higher voltages and be more compatible with the naked eye and easier to regulate to give evenness of illumination.

A tungsten-filament lamp with a filter cutting out all radiation beyond 550 nm looks pale green. The voltage setting for second-generation night goggles with this filter in use becomes about 10 volts (1850 K) and the lamp is now only ten times too dim for the naked eye. Subjectively, the light only looks about three times too dim and is actually useable. Further reduction in wavelength limit results in increasingly blue lighting which is not useable with coloured maps and in which the human eye has problems with focussing. For third-generation goggles, much of the visual wavelength range is not detected. A more complex filter can therefore be designed to have radiation fully compatible with the goggles and the naked eye. The colour will be from pale green to colourless, depending on design.

Interference filters could be used over all flight instruments and self-luminous items but this may prove to be too expensive. The simpler solution proposed in this paper and gradually being incorporated in UK Service helicopters is to switch off all instrument lighting and use a few, specially filtered tungsten-filament floodlamps and other light sources without infra-red radiation such as electro-luminescent panels. Some self-luminous items will still, however, be filtered and/or dimmed.

4.1 Filtered floodlights

UK helicopters such as Puma, Lynx and Gazelle carry general purpose 'wander lights' which are low wattage (3.5 watts) dimmable lamps on demountable, swivel fixings. These have been filtered in experimental installations and remounted to light the flight instrument panels from the front, while the normal instrument lighting is turned off.

There are a few dyed-glass filter materials which give a high degree of absorption of the near infra-red wavelengths beyond 600 or 650 nm. Typical is Scott BG 18 (Fig 2), which has a maximum transmission of 72% and looks medium-green. Others are BG 14, 23 and 38.

Good results have been obtained using BG 18 filters and ground glass diffusers fitted to the standard 'wander' lights[4]. The lamps are fitted with dimming resistors which have ample range for the purpose. Two or more lamps have been used in the RAE Sea King and in Army Gazelles and give reasonably even illumination, though with some problems of shadowing of instrument faces and needles.

When set for night goggle use, this floodlight instrument illumination is soft and even without the overloading effects evident with 'super-dim' integral illumination. The instruments *can* be read by the naked eye at this setting though a *small* increase in illumination is beneficial.

The standard aircrew torch fitted with a BG 18 filter and diffuser is very suitable for naked-eye map reading and causes no degradation of the adjacent pilot's goggle picture. All the colours on standard maps can be distinguished with contour lines enhanced and red features reduced to brown.

4.2 Filtered spotlights

An alternative system which has been considered, though not tested, is a remote spotlight with a suitable filter and closely controlled beam. This light or several similar units could be mounted a metre or more from the panels to be illuminated. The optical design would be such that the beam just fills but does not spill over the edges of the panel concerned. Shadows should thereby be much reduced but care must be taken to avoid direct reflections of the lamp in instrument faces or other shiny surfaces.

4.3 Electroluminescent panels

ELPs have been used[4] experimentally to illuminate the main instrument panel. Since these emit no infra-red, they do not need filters. ELPs can be fitted under the glare-shield over quite large areas and operated at low surface brightness. These panels, being very thin and flexible are very inconspicuous when fitted compared with the rather cumbersome appearance of separate tungsten-filament lamps and spotlights. ELPs can be made in various colours, including near-white and have high photometric efficiency since no infra-red light is emitted (Fig 3).

5 MEDIUM-TERM IMPROVEMENTS TO COCKPIT LIGHTING

Existing cockpit lamps, suitably modified, and ELPs are suitable for much of the cockpit illumination required and give excellent results at low cost and weight.

Cockpits however contain such items as warning panels and lights, back-illuminated legends on control panels, LED displays, tungsten-filament alpha-numeric displays and internally-illuminating push-buttons using tungsten-filament bulbs.

All these items rely on self-illumination for their function and cannot usefully be illuminated by external means.

In the short-term situation, 'super-dim' lighting may be necessary on some items, particularly those which contain tungsten-filament bulbs and which cannot be easily filtered. This category might include tungsten-filament-illuminated control panels and push-buttons. Warning panels and lights, and both types of alpha-numeric displays can also usefully be fitted with pale-coloured IR-absorbing glass filters which need not be removed when not using night goggles.

Cathode ray tubes and other phosphor displays emit little or no near infra-red energy and therefore are either immediately compatible with night goggles or require modest filtering or dimming.

6 THIRD-GENERATION IMAGE INTENSIFIERS

Early development samples of 18mm microchannel intensifiers for night goggles using third-generation photocathodes are available now but production units are unlikely to be available before 1984.

Fig 1 shows the spectral sensitivity curves for second- and third-generation intensifiers, though not to the same vertical scale. The peak sensitivity of the latter is about three times as high as present second-generation intensifiers.

It is seen that third-generation intensifiers are not sensitive to ultra-violet, blue and green but are very sensitive to yellow, orange, red and near infra-red. Consequently, equipment and displays to be seen through the goggles must be in the yellow to infra-red band. The peak sensitivity is several times as high as second-generation intensifiers and therefore it is expected that the goggles can be used at lower ambient light levels. Under these conditions, with the gain near maximum, cockpit lighting must be at a corresponding low level at the wavelengths in which they are sensitive.

In order to maintain the advantages of naked-eye-compatible cockpit lighting, it may be necessary to employ the blue-green part of the spectrum for naked eye purposes only. At the time of writing, the author has not yet carried out cockpit lighting experiments with third-generation goggles but no particular problems are anticipated and certain advantages are foreseen.

7 FUTURE NIGHT GOGGLES AND COCKPIT LIGHTING

It is unfortunate that the UK single tube night goggles for helicopters (Bittern) will not now go into production. The goggles, made by PPE, had advantages in weight and low-light performance over the AN/PVS-5A but the single tube correlated noise problem and unforeseen human factors effects made them unacceptable for 'nap-of-the-earth' helicopter flying.

The exceptionally large aperture objective lens of the Bittern design enable the RAE to develop a new cockpit lighting and instrument focussing system (based on earlier work in the USA) which will now be described[4]. Other methods of instrument focussing will also be described in a later section.

7.1 The RAE complementary filter/shared aperture system

The aperture of the goggle's objective lens is shared between cockpit viewing and outside-world viewing by a concentric filter-lens unit. Fig 4 shows the principles of operation when second-generation image, intensifiers are used. The inner zone of the objective lens unit carries a small, weak power, positive lens whose focal length equals the typical objective lens to instrument panel distance. This lens was made of short-pass, dyed-glass filter material. The outer zone is a plane-parallel, dyed-glass, long-pass filter. For the Bittern unit, using a second-generation image intensifier and a 31mm diameter objective lens, the small centre lens was about 6 mm diameter and the outer zone filter 50% transmission point of about 585 nm was used.

The outer zone therefore transmitted *only* light wavelengths larger than about 550 nm. The cockpit was then illuminated *only* with light of wavelengths shorter than 550 nm. The outer zone therefore could not transmit cockpit imagery but produced a focussed image of the outside world over the full field of view of the goggles. The centre lens transmitted cockpit lighting and acted as a 'close-up' correcting lens so that, with the objective lens focussed on infinity, instruments were simultaneously brought to a sharp focus over the full field of view of the goggles.

For this RAE, second-generation system the centre lens was made of Schott BG 18 filter glass which transmits the short wavelength cockpit light while blocking most of the mostly long wavelength outside-world light. The outer zone was made of Schott OG 590 filter glass and the cockpit lighting was by floodlights using filters combining BG 18 and an interference filter to give a 545 nm cut-off.

This RAE system[4] differs from the original USA ideas[6,7] in two respects. A centre lens is used instead of the pinhole in the USA system and a 545 nm rather than 500 nm filter system was used. The pinhole relied on a very large depth of field to incorporate the instrument panel distance but suffers from poor resolution. Also, because of its small size, the cockpit had to be flooded with high intensity lighting which was obviously impractical. The RAE small centre lens gives a true focus on the instruments and is large enough to allow a reasonable cockpit light level to be used. The fact that the cockpit lighting is of short wavelengths also enables it to be more compatible with naked-eye viewing, as explained in section 4. In fact, the RAE system resulted in cockpit lighting which was perfectly suitable for naked-eye viewing and, *without adjustment*, perfectly suitable for complementary filter night goggle viewing.

The depth of field is of the order of ±150 mm compared with ±35 mm with manual focus or bifocal goggles. This depth of field is sufficient to encompass most of the instrument panels in a variety of helicopters with different pilots. The main exceptions are overhead consoles and the rearward end of centre consoles.

If 'see-around' goggles are used, as suggested later, these other areas can be seen directly but *only* with the sufficient level of illumination provided with this system.

The USA system, using the smaller aperture objective lenses, could not afford loss of outside-world performance and therefore used a 500nm filter system. This gives deep blue cockpit lighting which is difficult to produce and very unpleasant for naked-eye use. With the Bittern lens, or with third-generation intensifiers a much higher filter wavelength, such as 650 nm, giving almost colourless, 'white', lighting is possible.

The strict wavelength limits for cockpit lighting are more stringent than the IR-cut lighting mentioned in section 4 but the principles of separate floodlights described there are suitable and were used for complementary filter focussing. For tungsten-filament bulb lighting, suitable glass or interference filters are available. For phosphor-based lighting, having no infra-red content (Fig 3), a simple gelatine or plastic filter is suitable, provided that the basic phosphor colour is not orange or red with second-generation intensifiers. Similarly, green and yellow LEDs can be filtered with plastic filters. Red LEDs and, in fact, any red lights cannot be used with this system (with second-generation intensifiers) since they have virtually no emission below 570 nm.

If this complementary filter system is used with second-generation intensifiers, certain points must therefore be borne in mind.

(1) Red and orange lights, panels, etc should only appear in exceptional circumstances. They cannot be suitably filtered to below 570 nm and therefore will appear out-of-focus and also cause some blurring of other instruments illuminated by them.

(2) There will be a loss of performance for the outside-world scene. This is a direct consequence of the annular, long-pass filter on the objective lens. The OG 590 filter loses about 10% to 20% in starlight (where infra-red predominates) and up to perhaps 40% in moonlight (where there is a lower proportion of infra-red). The high aperture lens of the Bittern goggle was able to sustain these losses for the sake of improved cockpit viewing but the standard AN/PVS-5A goggle cannot afford any loss of performance. It is recommended therefore that the complementary filter/shared aperture focussing system is *not* used with second-generation AN/PVS-5A goggles or others of similar performance. Third-generation intensifiers with their higher performance and high infra-red sensitivity will allow the system to be used even with modest objective lens apertures and 'white' lighting.

(3) Direct moonlight will illuminate the cockpit with light of longer wavelengths than are specified for this system. This causes superimposed out-of-focus images which can be largely eliminated by introducing a push-on or fold-down, circular stop on the objective lens. Goggle performance in bright moonlight is adequate and stopping down the lens may even improve performance. The relative area of the centre lens is thus increased and the blurring effect is reduced by a factor of four, for a half-diameter stop, which is adequate for the high contrast instruments.

Additional measures to be taken include the fitting of green filters and/or 'light control panels' to illuminated panels and buttons and light control panels have been tried on the flight instruments themselves[8]. These measures are discussed in section 8.

7.2 'See-through' goggles

The shared aperture system described above, although offering several important benefits, still suffers from certain fundamental disadvantages.

(1) There is still a restricted field of view.

(2) The resolution is poor compared with the naked eye.

(3) The image is monochrome and cannot distinguish between colours.

(4) The depth of field is limited.

(5) The cockpit and instruments are unnaturally enlarged and move in an exaggerated way when seen through goggles. This is because the objective lens is some distance in front of the eyes and closer to the instruments and also moves in a large diameter arc with head movement.

If goggles could be made in which a beam splitter enabled a direct view to be seen in addition to the intensified image, the problems outlined above would disappear.

The USA ANVIS goggles AN/AVS-7 have small-diameter optical assemblies and are of open construction with the intention of giving a 'see-around' capability. At the present time, the US Army is using the 'super-dim' lighting system for goggles which would not allow the pilot to see anything when looking around the goggles at the instruments!

The only feasible solution to this problem is to use the complementary filter lighting system but without a shared aperture lens. If cockpit lighting is restricted to short wavelengths and a long-pass filter used on the goggles, the latter will then see virtually nothing inside the cockpit. The cockpit however will be visible with either the 'see-around' ANVIS concept or the 'see-through' concept.

The 'see-around' design has the advantage of simplicity but the pilot must look at least 20° off-axis to see the instruments. The RAE will be investigating both full field and partial 'see-through' eyepiece systems to supplement the 'see-around' capability. The designs are not yet complete and depend on such constraints as eye-relief distance, length and weight. An extension of the direct vision area into the part of the field of view which would be used by the bifocal system would give advantages over both bifocal and simple 'see-around' systems.

It is thought that a completely superimposed direct and intensified field of view may not be required and is likely to be technically difficult to achieve. Fig 5 shows simplified diagrams of 'see-through' designs. The most likely arrangements are the top two designs in which the intensified view is on axis to the eye and the 'see-through' periscope has the offset axis. The most important constraint is the eye relief distance which is better with this design than with the alternative, offset intensifier axis. It is hoped that the periscopic unit itself will be designed to give maximum angle of view and minimum obstruction to 'see around' it. There will of course be about 40 mm of parallax between the 'see around' and the periscopic 'see through' views but it is hoped that this will not matter particularly if these two axes are slightly converged to the instrument panel distance.

It will be important in 'see-through' designs to balance the levels of cockpit illumination to the intensified view of the outside world so that the eye can cover the full range of tones available. Windscreen pillars and other aircraft structure will appear in silhouette through the intensified path and will be at more than unity magnification and suffer some parallax shift. There is also a potential problem arising from the automatic gain control in the image intensifier tubes. If 'see-through' goggles with complementary filter lighting are directed mainly into the cockpit, the part of their field of view covered by the outside-world image is reduced or disappears entirely. Since the goggles cannot 'see' inside the cockpit, their gain will increase considerably giving an out-of-focus, noisy, enlarged image of the cockpit caused by stray, ambient, 'white' light in the cockpit.

These and other possible problems must be solved before 'see-through' goggles are introduced. The principles of separating the cockpit and outside-world images by means of complementary filters must in any case be maintained to avoid a hopeless and confusing overlay of images. The map reading problem with its need to look almost directly downwards to a map on the knees is also difficult and an angled direct view has been proposed.

8 LIGHT CONTROL

The phrase 'light control' is intended to cover the requirements to direct the cockpit lighting in the required direction and control incoming external light and reflections.

Matt black paint has been developed which should be used to cover as many surfaces as possible and reduce scattered light. Structural alterations such as extending the glare shield over the main instrument panel and fitting rubber hoods over some instruments may be required. These would reduce both incoming 'white' light, in the case of 'shared aperture' or 'see-through' complementary filter systems and prevent self illuminated or floodlit instruments from being seen reflected in the windows.

The 3M Corporation manufacture a micro-louvre plastic sheeting called 'light control panel' which acts like miniature venetian blinds. Light can only be transmitted through this sheet over a restricted range of angles. Types are available which give high transmission normal to the sheet, falling off to zero at 30^{o} to the normal. Other versions give transmission to wider angles to the normal, high transmission at angles other than zero (*ie* angled louvres) and two sets of louvres at right angles. Non-shiny and abrasion-resistant finishes are available. The sheet is made in thicknesses from 0.75 mm to 2.8 mm.

This material can be used to prevent angled, ambient illumination from falling on a back-illuminated instrument or panel surface and also prevent the light from such instruments from being emitted over angles which would cause excessive scatter or reflections[8]. Electro-luminescent panels fitted with light control panels will emit light only over the required angles instead of over almost a hemisphere. Thus, ELPs under the glare shield can be designed to shine only on the instrument panel and not on the pilot's knees, floor and elsewhere. Equipment, such as cathode-ray tubes and other displays can be fitted with light control panels to prevent their being seen by and causing distractions to another crew member. The louvres are at about 0.25 mm spacing and will not, normally degrade the resolution of displays.

9 HELICOPTER VULNERABILITY

Any radiation emitted by the helicopter at night can be used to detect and recognise it. Long-wave infra-red radiation (longer wavelength than 3 μm) from hot exhaust pipes is a known hazard and steps are being taken to reduce it. Visible and near-IR light can be seen either visually or by image intensifiers. Ultra-violet and blue light is most strongly scattered by the atmosphere while near infra-red light is well transmitted and within the spectral sensitivity range of second and particularly third-generation intensifiers.

There are four types of lighting which may be used in helicopter cockpits:

Type 1: Normal instrument lighting for naked eye use.

Type 2: 'Super-dim' instrument lighting for goggles.

Type 3: Non-infra-red lighting for either normal focussing or complementary filter systems (shared aperture or see through).

Type 4: Ultra-violet light for use with UV-activated phosphors on instruments for naked eye or goggles viewing.

For naked-eye detection, the ascending order of detectability will be 2, 4, 3, 1. Type 2 emits only very low-level near-IR. Type 4 has an almost invisible light source but glowing instruments. Type 3 could be brighter to the eye than 1 unless particular care is taken.

For detection by image intensifiers, the order becomes difficult to judge since the cockpit lighting has been set for an image intensifier device (the goggles) and each type will presumably emit approximately the same amount of light as far as the goggles are concerned.

It is suggested that the UV phosphor system is useful for minimum detectability, coupled perhaps with a limited display of flight symbology in the cockpit. Head-up displays have also been investigated for use with night goggles in helicopters and are quite useable though having certain disadvantage of cost, weight and field of view compared with goggle-mounted symbology.

It is doubtful if these levels of light output add to the detectability of helicopters at night when other factors such as silhouetting, noise or moonlight glint may be more important. It may be considered that a dual system should be fitted with naked-eye-compatible lighting for see-though or shared aperture goggles and ultra-violet, head-up display or goggle-mounted symbology for a covert system when needed.

10 CONCLUSIONS

It is generally agreed among European nations that night goggles will be of considerable use in small military helicopters until such time as night vision equipment of superior cost-effectiveness and reasonable cost and weight is widely available.

Every effort therefore needs to be made to optimise the goggle-cockpit system while retaining the flexibility of simple night goggles. There is no easy solution to the numerous problems posed by night goggles in helicopter cockpits and goggles could evolve along one or more of several different lines of development mentioned earlier.

However, using present-day night goggles, a considerable improvement can be made to cockpit lighting by suitable filtering out of infra-red radiation from tungsten-filament lamps and by attention to reflections. In the longer term, further improvements along these lines can be made by modifying and redesigning flight instruments and controls with night goggles in mind. Improved methods of focussing on instruments and maps are being developed and will be introduced with the new generation of image intensifiers. In conclusion, provided that certain principles are adhered to, it is not too costly and unreasonable to design future cockpits to complement the undoubted usefulness of night goggles rather than try to modify cockpits to some compromise solution.

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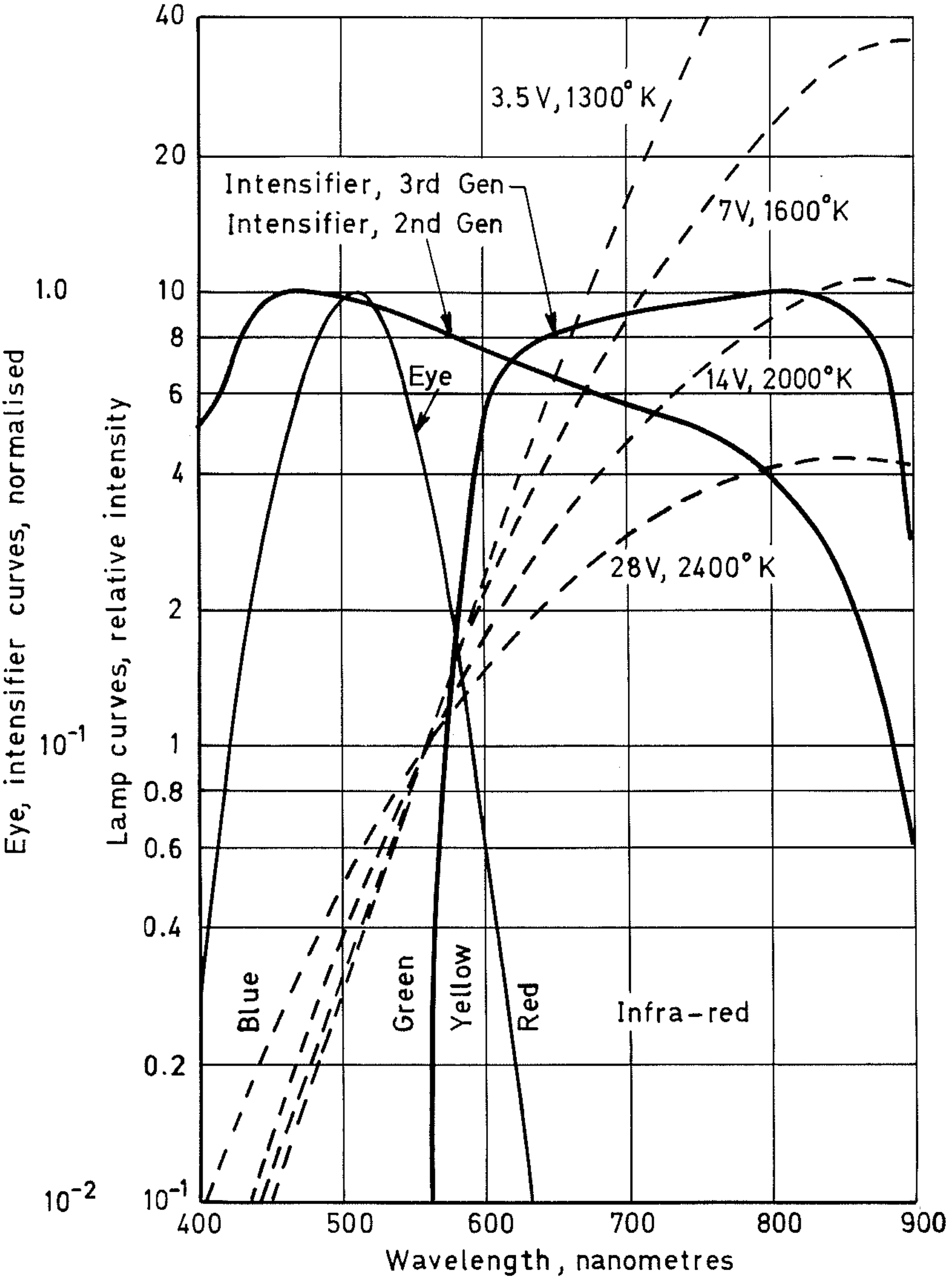


Fig 1 Human eye and intensifier sensitivities and tungsten-filament lamp spectra for 3.5 to 28 volts

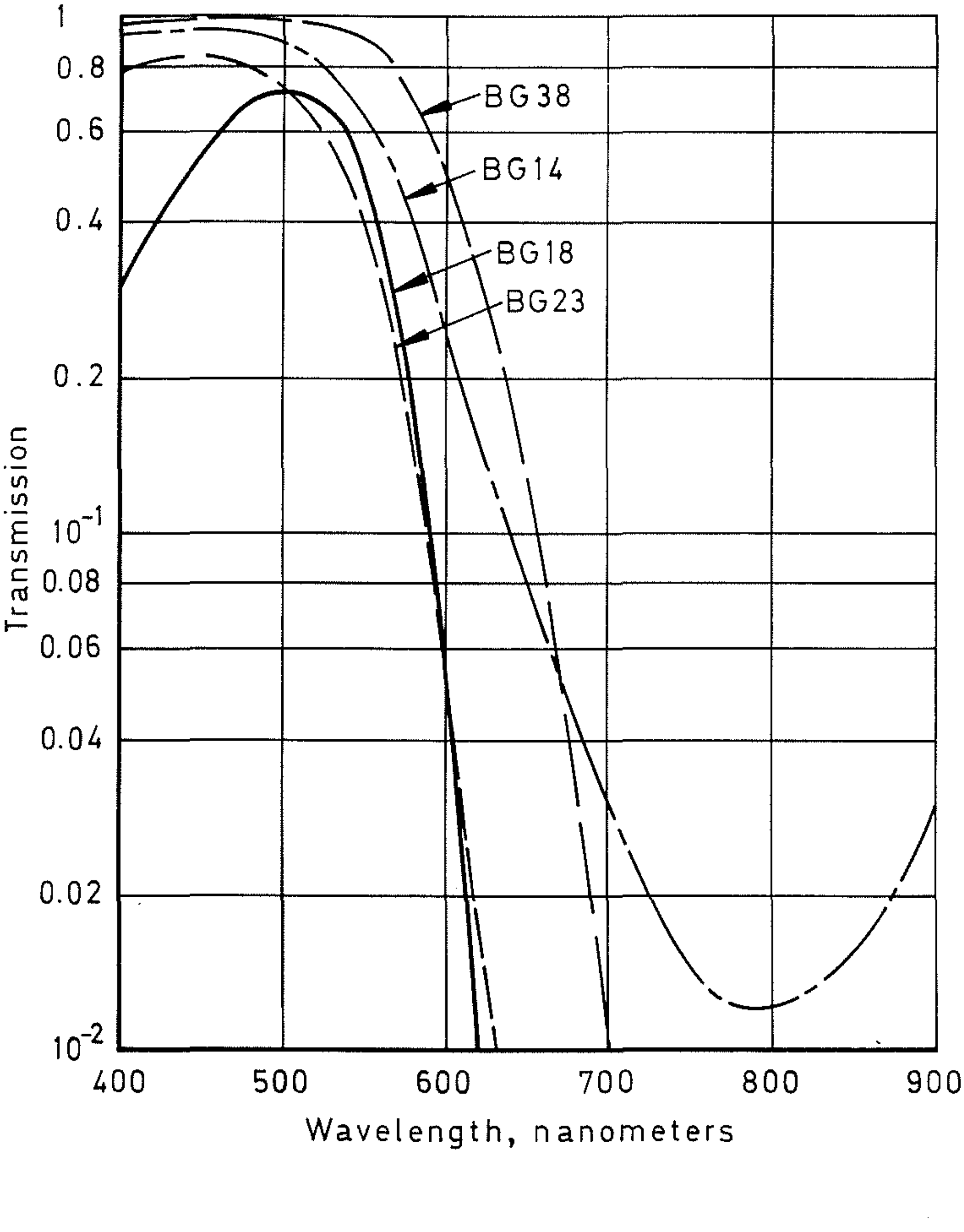


Fig 2 Spectral transmission of Schott filters

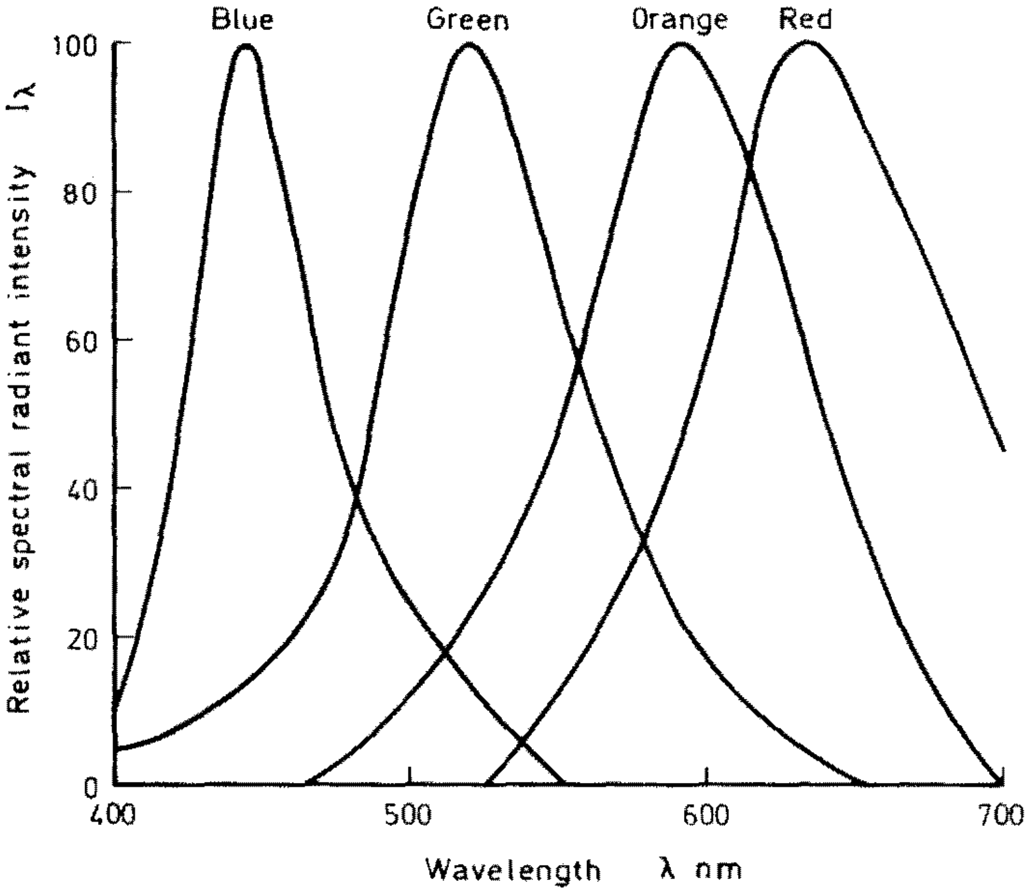


Fig 3 Spectra of typical phosphors used in electroluminescent panels

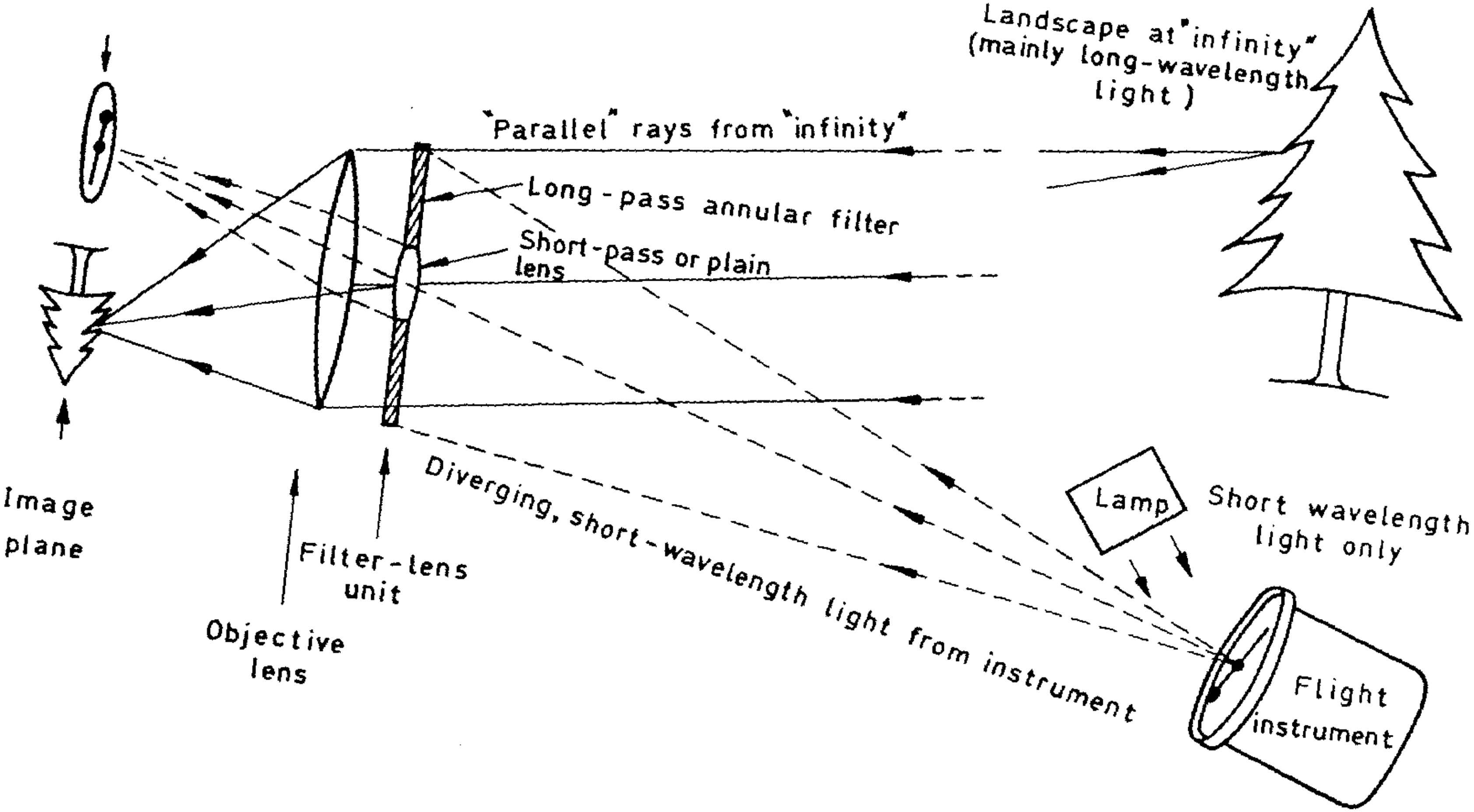
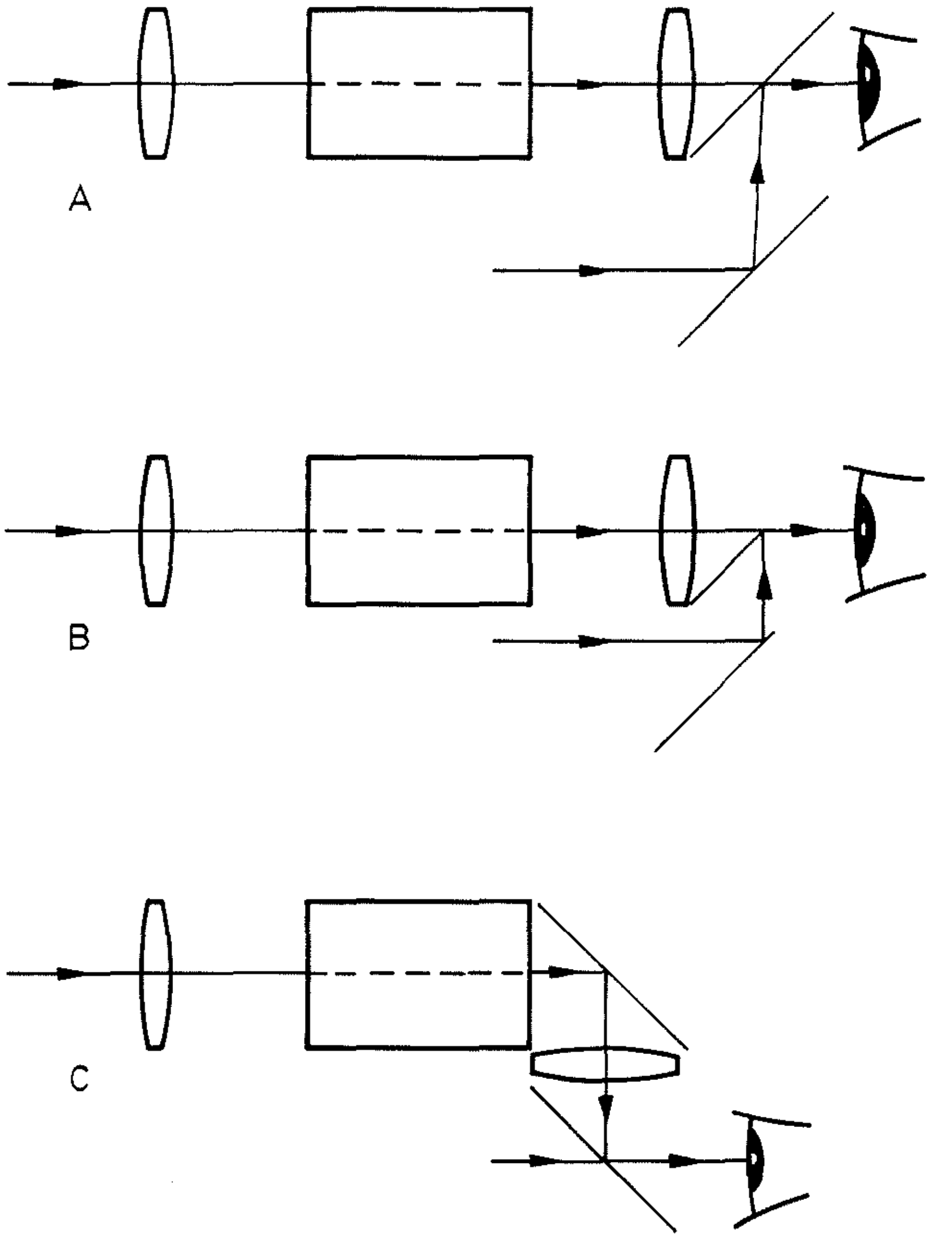


Fig 4 Principles of operation of complementary filter-shared aperture system



A - Full-field, offset, direct view

B - Half-field, offset, direct view

C - Full-field, in-line, direct view

Fig 5 Some possible variations of 'see-through' goggles