Annex 1

Report from the Institute of Ophthalmology, UCL, London:
"Spectral and temporal characterisation of Photochromic eyewear"

London, November 30, 2006

Spectral and temporal characterisation of Photochromic eyewear

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Version 2

Description of eyewear

Lenses in photochromic glasses darken on exposure to UV light. Once the UV source is removed the light transmission of the lenses increase.
A photochromic material achieves its reversible property through the embedding of microcrystalline silver chlorine in a glass substrate, which changes its chemical structure after absorbing ultraviolet light. The UV light causes the photochromics to absorb a dye, and then change back to clear when the UV source is removed.
Fading and activation of photochromic compounds is regulated by a thermal process and is therefore temperature dependent. Photochromic eyewear consequently reaches higher absorbency at lower temperatures. The photochromic absorbency function is inversely related to the ambient temperature resulting in increased density in cold weather conditions [1-4].

The lens manufacturer is unknown. The tested lenses are made out of glass and have a brown tint caused by the photochromic material, which coats the anterior surface of the lenses, and as a result have a relative higher absorbance of shorter wavelengths, including blue, than that of longer wavelengths.

Methods

Three aspects of the performance of the photochromic lenses have been characterised:

- Photochromic activation as a function of time

- Photochromic fading as a function of time
- and Lens transmittance spectra as a function of ambient spectra.

The lenses were initially kept in complete darkness for 30 minutes to de-activate the photochromic effect, while for the second test the lenses were activated to maximum absorbance using a standard optometry UV light excitation source. The temperature was kept at a constant 23°C throughout the tests. All spectroscopic recordings were made with an Ocean Optics SD2000 Spectrometer *(San Jose, CA, USA)*, which was interfaced with a personal computer using AvaSoft spectrometer software v. 6.1 *(Eerbeck, Holland)* on Windows *(Microsoft, Seattle, WA, USA)*. The output data was processed in MatLab R14 v2006b *(MathWorks, Natick, MA, USA)*. The ambient light level, measured with a photometer *(IL700, International Light Technologies, Peabody, MA, USA)* was 900 candela/m^2 throughout the experiment.

Results

The optical density of the lenses was 20% after 30 minutes in complete darkness, but would rapidly increase to 48% after ten minutes of activation under normal daylight ambient light levels *(figure one)*. The data points were modeled as a logarithmic function.

Maximum optical density was achieved by exposing the lenses to UV-light after which the glasses were left in normal ambient daylight for ten minutes. The initial optical density of the lenses was 77% and it decreased to 37% after ten minutes in daylight *(figure two)*. These data points were modeled as an exponential function.

The spectral transmittance of the photochromic lenses was measured at each time point and subtracted from that of the ambient light *(figures three, four and five)*. Transmittance was higher at all time points in the longer wavelength resulting in the brownish tint of the lenses.

Conclusions

The minimum optical density of the tested photochromic lenses was measured to be 20%, which was achieved after leaving the glasses for 30 minutes in complete darkness. Although the ambient light levels and spectra on the deck at the time of the accident are not known, we can state that the optical transmission of the lenses could not have been more than 80%. This compares with 94.7% and 99.4% optical transmittance of uncoated and coated lenses, respectively *(figure six)*. However, taking all ambient factors into account, including any illumination from instrumentation on the deck, reflections from the windows and the latency of the photochromic fading, the optical transmission of the lenses would probably have been less.

We have not studied the effect that such a reduction in transmission would have on central and peripheral vision and the ability of a subject to detect monochromatic light sources against a dark background. It would not, however, be incorrect to assume that a uniform reduction in brightness due to the optical density of the lenses would decrease the likelihood that a subject would detect the lights of shipping vessels [5].

1. Caurant, D., Gourier, D. & Vivien, D. Bleaching mechanism of silver halide photochromic glasses. *J. Appl. Phys.* **73**, 1657-1668 (1993).
2. Megla, G. K. Optical Properties and Applications of Photochromic Glass. *Applied Optics* **5**, 945-961 (1966).
3. Ross III, D. F. Ophthalmic lenses: Accuratly characterizing transmittance of photochromic and other common lens materials. *Applied Optics* **30**, 3673-3677 (1991).
4. Smith, G. P. Photochromatic Glasses: Properties and Applications. *Journal of Materials Science* **2**, 139-152 (1967).
5. Eperjesi, F., Fowler, C. W. & Evans, B. J. Do tinted lenses or filters improve visual performance in low vision? A review of the literature. *Ophthalmic Physiol Opt* **22**, 68-77 (2002).

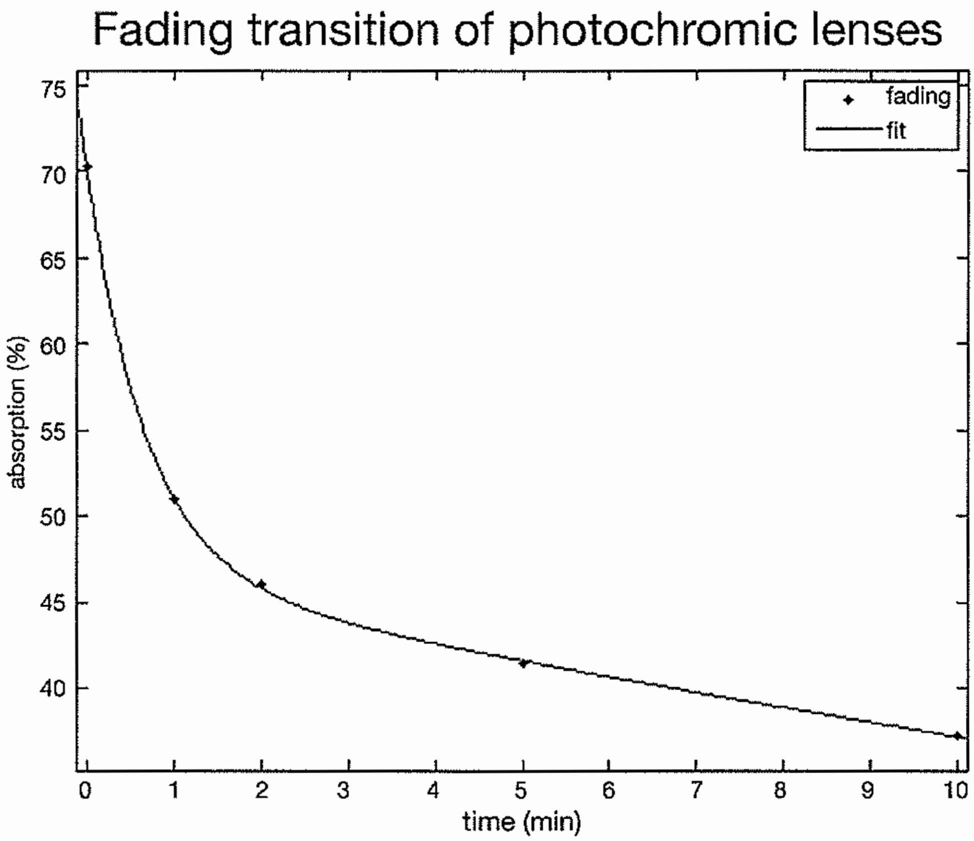

Figure 1 Light absorption of photochromic lenses as a function of time. Maximum density, 74%, was measured immediately after activation by UV light.

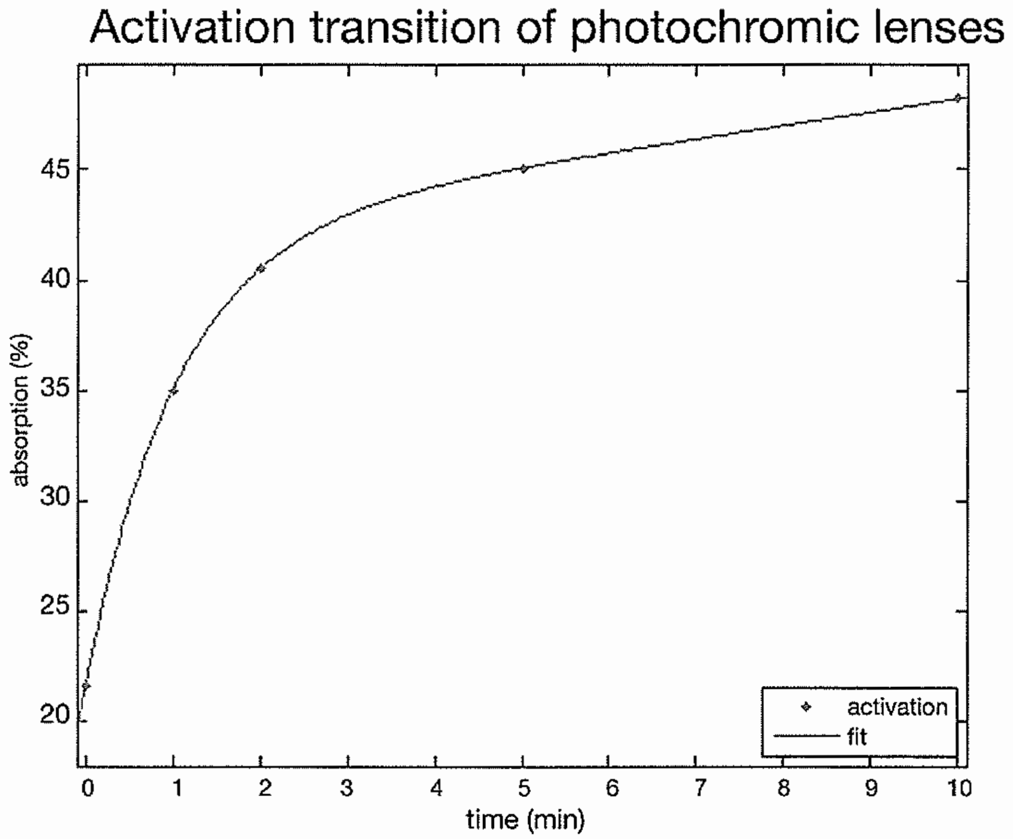

Figure 2 Light absorption of photochromic lenses as a function of time. After 30 minutes in complete darkness the lenses transmitted 80% of visible light (100% - absorption). After ten minutes in normal daylight transmission was reduced to 47%

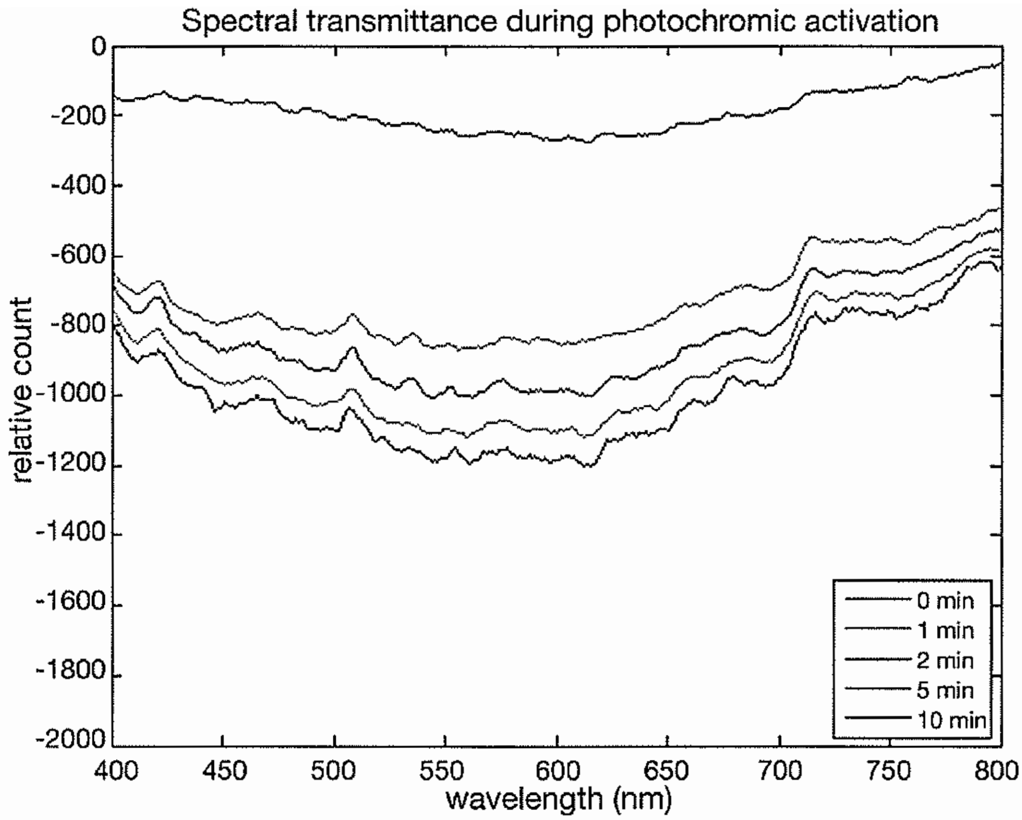

Figure 3 Spectral transmittance during activation. Y-axis represents arbitrary units subtracted (or absorbed) by the glasses. The photochromic tint is less saturated in darkness (0 minutes), but after one minute the brown hue appears as illustrated by the bump in the spectra at around 720nm.

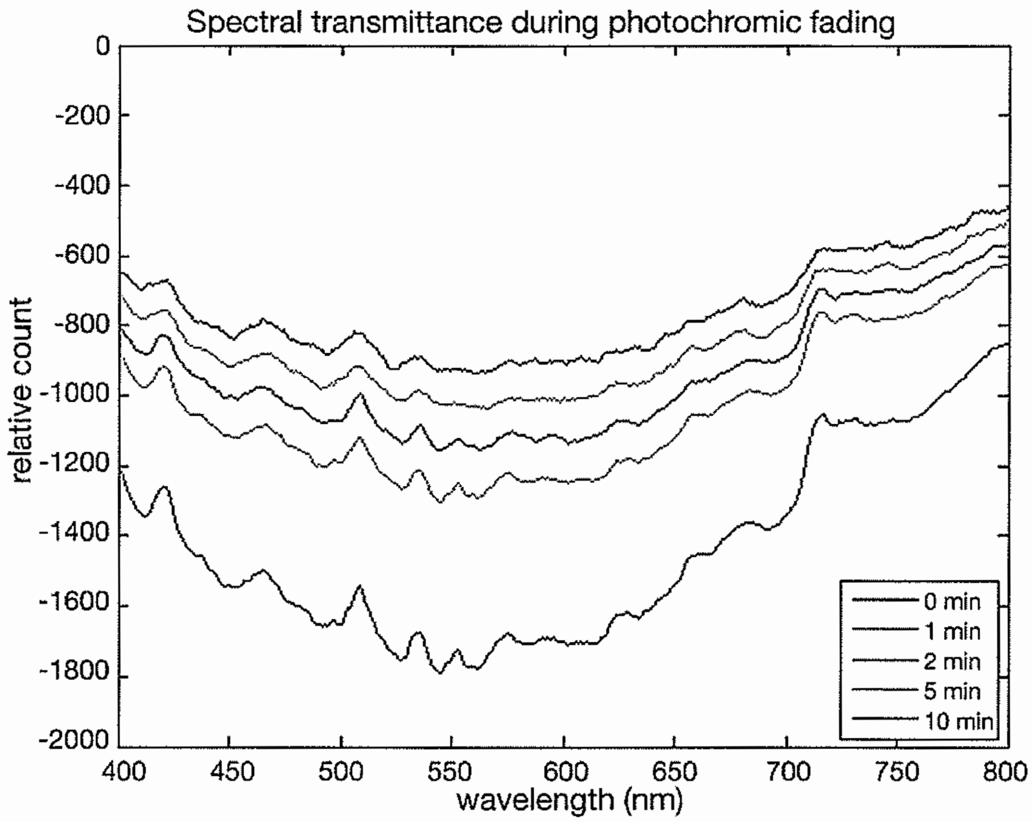

Figure 4 Spectral transmittance as a function of wavelength and time during fading. Y-axis represents arbitrary units subtracted (or absorbed) by the glasses. After ten minutes of fading the brown hue is still present in the lenses.

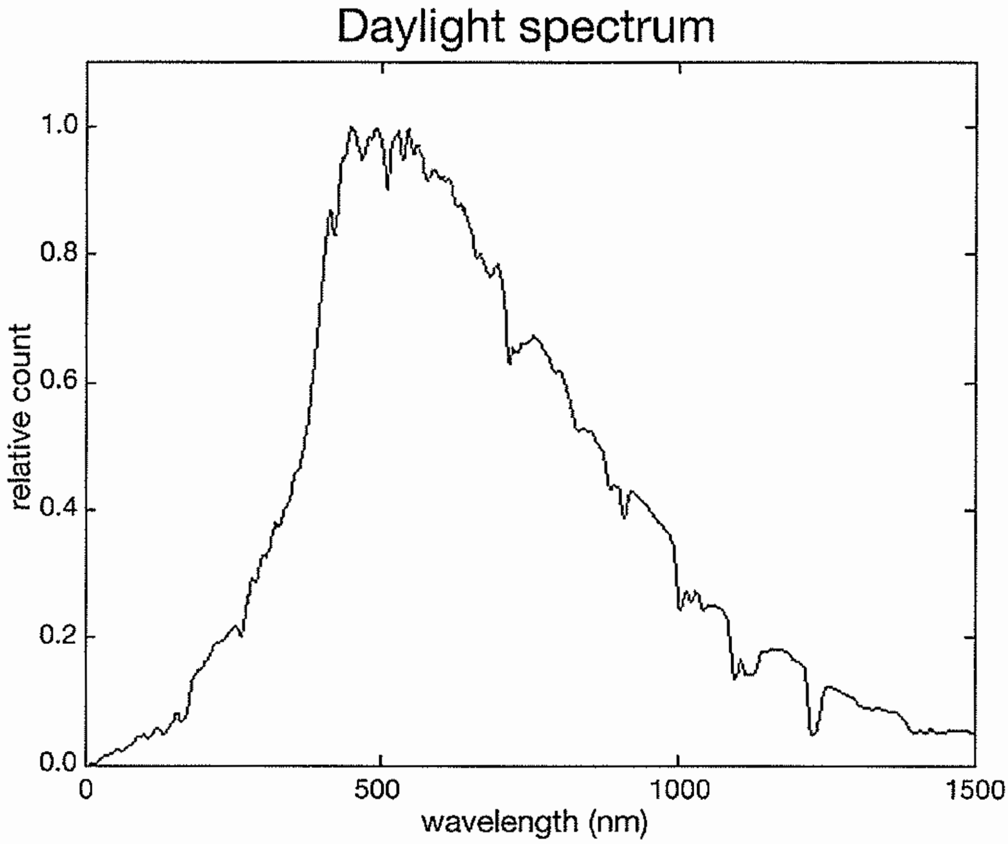

Figure 5 Daylight spectrum. The spectrum of the reference light used during the tests, representing a normal cloudy day.

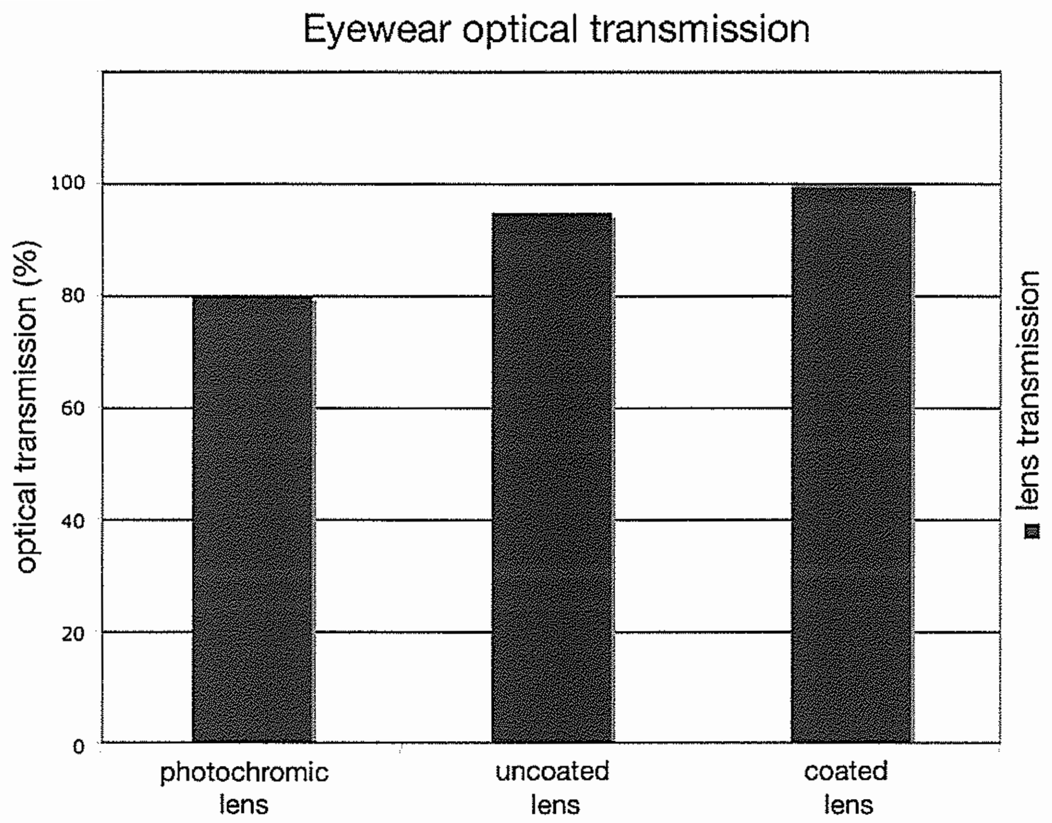

Figure 6 Optical transmission of the photochromic lenses compared with that of uncoated and coated lenses. Faded photochromic lenses, in their most translucent state, transmit much less light than do either uncoated, or coated lenses.

Annex 2

Report from the Institute of Ophthalmology, UCL, London:
"Spectral and temporal characterisation of Photochromic lenses"

Spectral and temporal characterisation of Photochromic lenses

Glen Jeffery and Peter Lundh. Institute of Ophthalmology, UCL, London

Five sets of brown tinted photochromic lenses from the major manufacturers have been characterised. A sixth pair of lenses, evidence from a MAIB trial previously reported on, was included in the test for comparison. Fading and activation transition times were measured, as were maximum transmission and absorption, respectively. Finally, spectral transmission was measured as a function of time. Results showed that Lens A performed best in all aspects while the eyewear from the MAIB trial were the worst performers.

Description of photochromic eyewear

Photochromic glasses aid the wearer in maintaining optimal vision while moving between environments with different lighting conditions. Lenses in photochromic glasses darken on exposure to UV light. Once the UV source is removed the light transmission of the lenses increase.

A photochromic material achieves its reversible property through the embedding of microcrystalline silver chlorine in a glass substrate, which changes its chemical structure after absorbing ultraviolet light. The UV light causes the photochromics to absorb a dye, and then change back to clear when the UV source is removed.

Fading and activation of photochromic compounds is regulated by a thermal process and is therefore temperature dependent. Photochromic eyewear consequently reaches higher absorbency at lower temperatures. The photochromic absorbency function is inversely related to the ambient temperature resulting in increased density in cold weather conditions Caurant et al., 1993, J. Appl. Phys., 73, 1657-1668,Megla, 1966, Applied Optics, 5, 945-961,Ross III, 1991, Applied Optics, 30, 3673-3677,Smith, 1967, Journal of Materials Science, 2, 139-152

Photochromic lenses, like sunglasses, significantly reduce discomfort glare and can improve on visual acuity and contrast detection in bright light conditions while reducing ocular fatigue. However, it is important that users are aware of the limitations of photochromic eyewear and that they are not used in critical low light level conditions Dain, 2003, Clin Exp Optom S, 86, 77-90,Lee et al., 2002, CLAO J S, 28, 80-2

Samples

To provide a representation of commonly dispensed ophthalmic materials, we purchased lenses of five materials from four manufacturers (see table one). All sample lenses were uncut and had a 70mm diameter. In addition we also tested eyewear supplied by MAIB. All lenses were plastic.

Measurement procedures and equipment

The transmittance to which a photochromic lens darkens in a given exposure situation depends not only on the intensity and spectral distribution of the incident activating radiation at the time of observation, but also on the lenses exposure history and its temperature.

Three aspects of the performance of the photochromic lenses have been characterised:

- Photochromic activation as a function of time
- Photochromic fading as a function of time
- Lens transmittance spectra as a function of time

The lenses were initially kept in complete darkness for 30 minutes to de-activate the photochromic effect, they were then activated by a broadband light source (900 cd/m^2). Spectrometer. For the second test the lenses were activated to maximum absorbance using a standard optometry UV light excitation source. Fading transition was thereafter measured in a tungsten-lightsource illuminated environment (75 cd/m^2). Temperature was kept at a constant 20°C throughout the tests. Lens transmission spectrum and density was measured as a function of time using Ocean Optics USB 2000 (San Jose, CA, USA), which was interfaced with a personal computer using SpectraSuite spectrometer software *(Ocean Optics, San Jose, CA, USA)* on Windows operating *system (Microsoft, Seattle, WA, USA)*. The output data was processed in MatLab R14 v2006b *(MathWorks, Natick, MA, USA)*. The ambient luminance levels, were measured with a Minolta CS-100A colorimeter *(Konica Minolta, Tokyo, Japan)*.

Results

Activation transition

Immediately after activation the optical transmission of the lenses varied between 75-90%, with the antireflection coated Lens A recording the highest transmission value and the MAIB supplied eyewear the lowest. After ten minutes of activation transmission varied between

20-30% with the antireflection coated Lens A performing the best and the MAIB supplied eyewear the worst *(figure one).* The data points were modeled as an exponential function.

Fading transition

Maximum optical density was achieved by exposing the lenses to UV-light after which the lenses were left in low indoor ambient light (75 cd/m^2) for ten minutes. The initial optical transmission of the lenses varied between 28-38% with the antireflection coated Lens A recording the highest transmission value and the MAIB supplied eyewear the lowest. After ten minutes in daylight transmission had increased to between 70-90% with the antireflection coated Lens A performing the best and the MAIB supplied eyewear the worst. *(figure two).* Data points were modeled as an exponential function.

Spectral transmission

The spectral transmittance of the photochromic lenses was measured at each time point *(figures three and four).* Lens B and Lens A were the best at absorbing short wavelength and UV light, while the MAIB supplied eyewear were the worst.

Conclusions

All of the photochromic coating tested resulted in significant reductions in the amount of transmitted light that could be important when the user was working in a dark environment. Lens A were the best performers in all respects with the hard multi layer antireflection coated (HMAR) lens further improving on the transmittance somewhat.
They had the overall highest transmittance in low luminance environments and the highest absorbance daylight conditions. They also had the shortest activation and fading times. The performance of the MAIB supplied eyewear was significantly inferior to that of the currently commercially available lenses indicating that either manufacturers have improved the performance of their photochromic materials, or that the performance of photochromic glasses is reduced with time.

Ultraviolet radiation absorption capability of the lenses was not characterised

Given these results over a range of different photochromic coatings we would have reservations regarding the use of photochromic glasses in dark environments or where significant and rapid changes in illumination were taking place and where the wearer was required to make critical decisions based on visual information.

Lens A	No coating	Brown 1.50
Lens B	Hard multi layer antireflection coating	Brown 1.50
Lens C	No coating	Brown 1.56
Lens D	No coating	Brown
Lens E	No coating	Brown
MAIB supplied eyewear	No coating	Brown

Table 1 Lenses tested

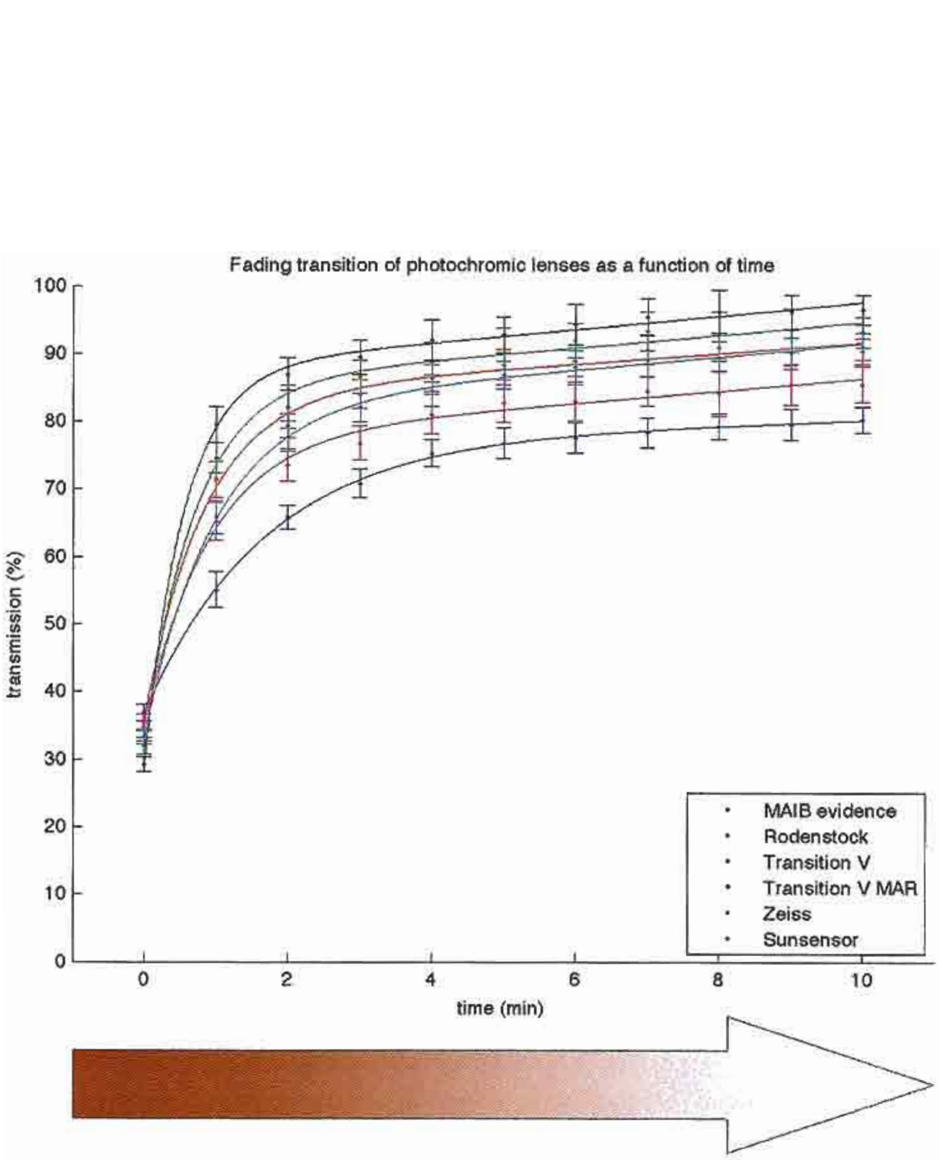

Figure 1 Fading transition as a function of time

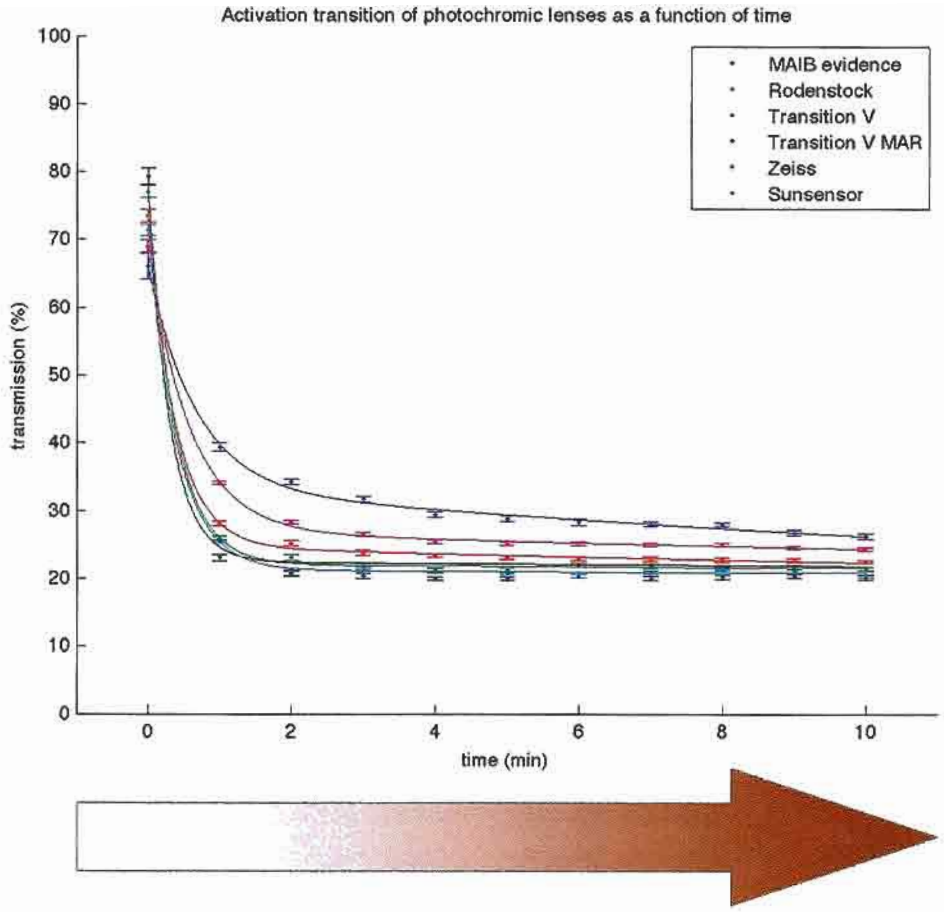

Figure 2 Activation transition as a function of time

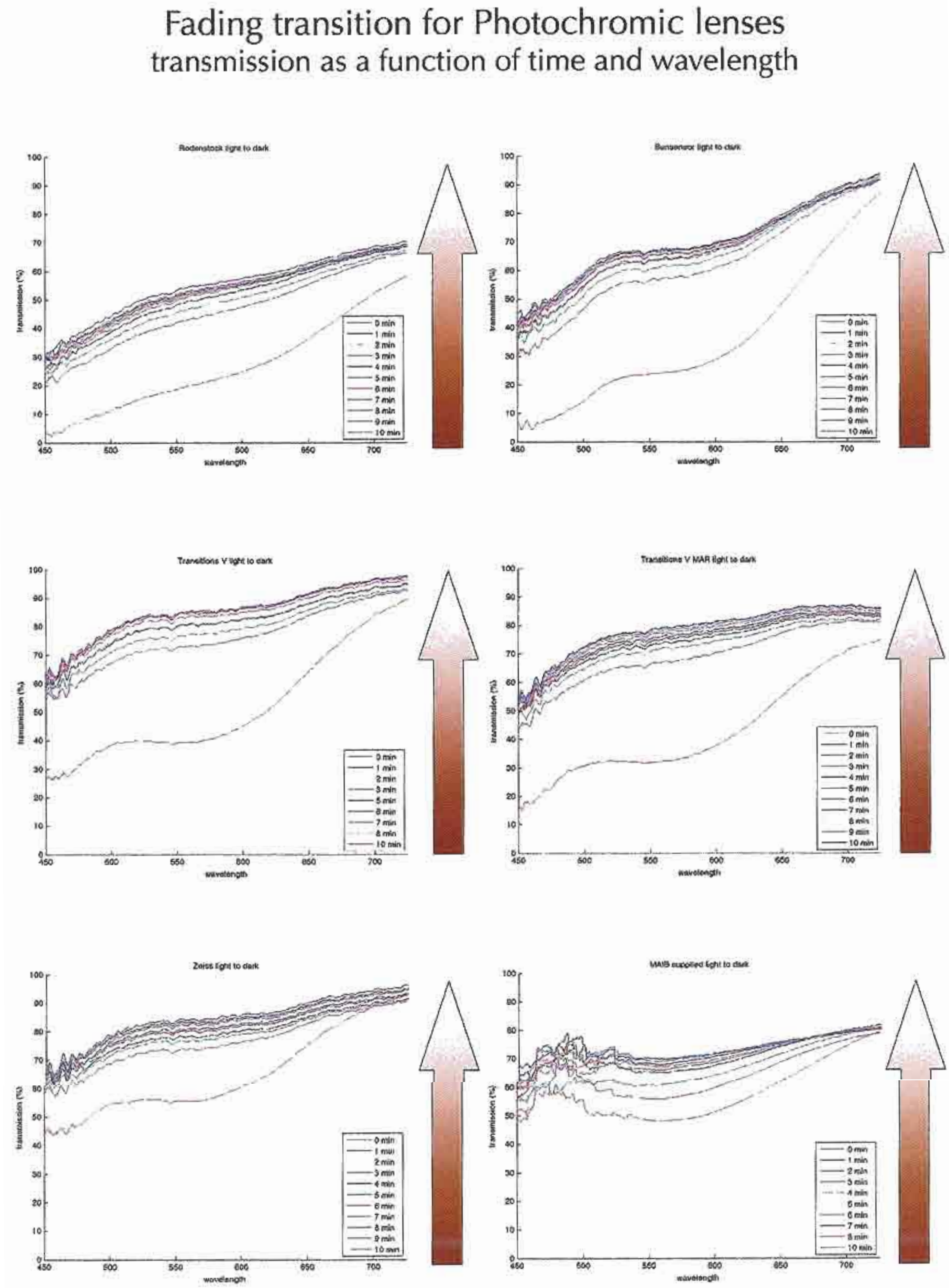

Figure 3 Fading transition for photochromic lenses as a function of time and wavelength

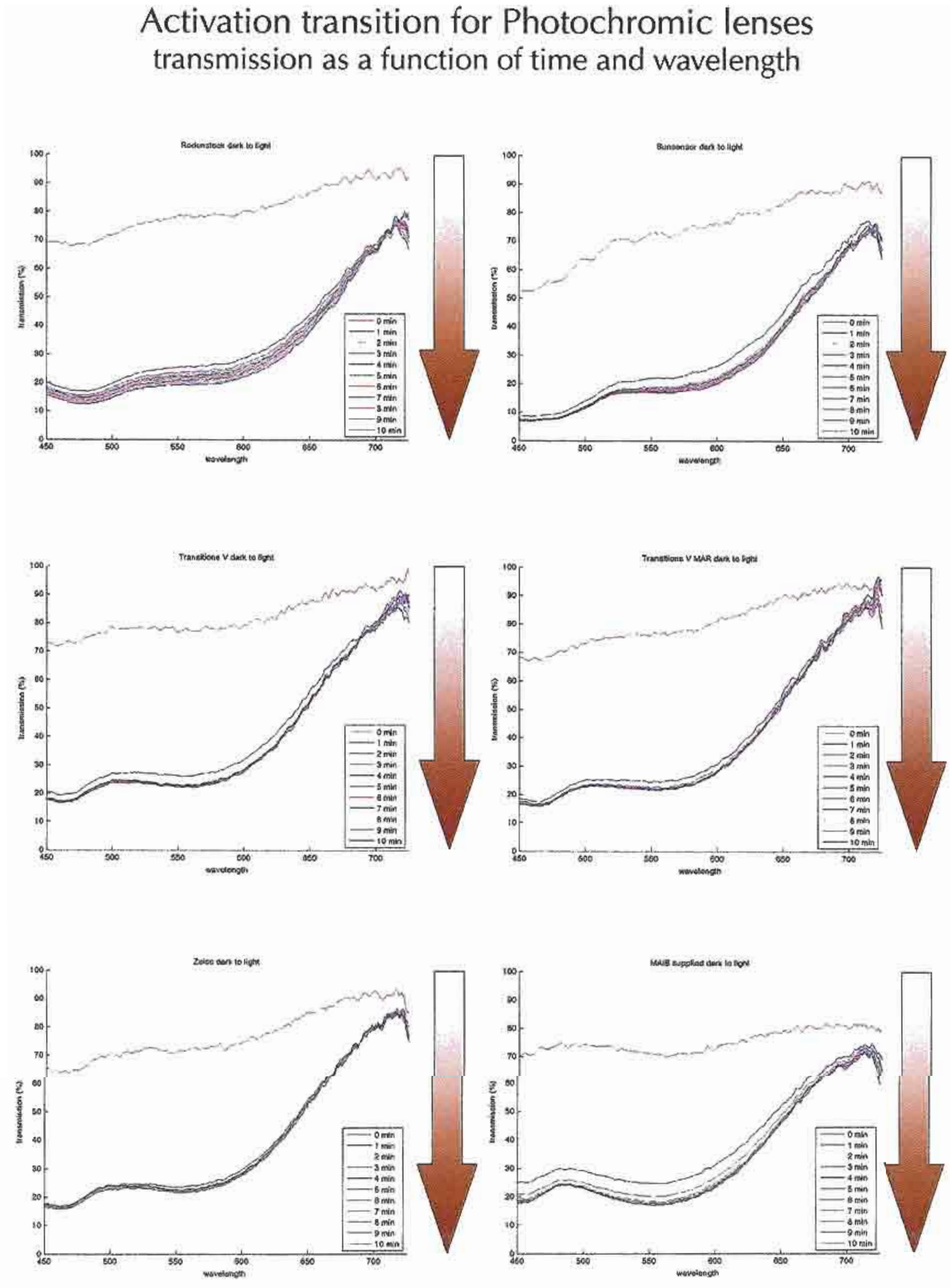

Figure 4 Activation transition for photochromic lenses as a function of time and wavelength

Annex 3

Report from the Institute of Ophthalmology, UCL, London:
"Report on the potential reduction in visual acuity resulting from photochromic glasses"

Report on the potential reduction in visual acuity resulting from photochromic glasses for Marine Accident Investigation Branch of The Department of Transport (Your reference 1/11/19).

1] Synopsis

A lookout walked into a ships wheel house to take over a watch during the hours of darkness. Nine minutes later the ship was involved in an incident that may have resulted in the sinking of a sailing vessel and the loss of three lives. From the Ophthalmic report of Mr James McGill the subject's vision, although corrected, was good and there were no indications of any underlying visual pathology. The conditions at the time of the incident were clear. The question asked is whether the light sensitive glasses worn by the lookout could have contributed to the incident?

2] The glasses

Attached is a separate detailed report on the optic quality of the photochromic glasses worn on the night of the incident. Three key questions were posed regarding these in the documentation provided on 10th November 2006. First, what would be the ability of the lookout to see shipping lights while wearing clear lenses? Second, what would the ability be of the lookout to see these lights while wearing the photochromic lenses supplied to us? Third, are photochromic lenses suitable for use by lookouts at night?

While it is possible to provide answers to these questions, it would be an oversight to answer them in isolation from details of the visual environment of the bridge on the night of the incident. While such information is at best qualitative, it needs to be taken into account. An analysis of this is provided below under section 3.

There is no reason to believe that the wearing of clear lenses would have any negative impact on vision in itself, as they would transmit approximately 95% of the environmental light. However, from the information provided below, there are compelling reasons to believe that the visual environment at the time of the incident would seriously compromise the ability of an individual to detect shipping lights independent of optical correction.

The photochromatic lenses tested allowed only 80% light transmition after 30 mins in total darkness. Hence, it is probable that they further compromised the ability to detect shipping lights. Consequently, these glasses are not suitable for use on a bridge at night.

3] The visual environment on the wheel house

An analysis of visual sensitivity of the lookout on the night of the incident is seriously compromised by the absence of key data. The precise level of environmental illumination and its sources are critical to understanding the ability of an observer to detect an object. Further, visual sensitivity (absolute thresholds) can decline with age normally by as much a one long unit (Stevens 1946: Pitts 1982). Given that the lookout was approximately 61 years old, age would probably be an additional factor.

The dynamic range of the human visual system to varied levels of illumination extends over approximately ten log units from visual threshold at full dark adaptation to bright light. In bright light we use cone photoreceptors that can mediate colour but have a no ability to resolve absolute thresholds. When fully dark adapted we use rod photoreceptors that are very sensitive but have no ability to discriminate colour. The two systems overlap slightly in a restricted range where both photoreceptor types can function, but not optimally. The lighting conditions where the two photoreceptor types overlap are analogous to those found around the time of sun set.

Had the lookout been in a totally dark environment his dark adaptation threshold would have been reached within approximately 30 mins depending on the stimulus size used to test threshold levels, with small stimuli (<1 degree) being significantly harder to resolve than larger stimuli. Adaptation thresholds will also depend upon stimulus colour (See attached Figures 7.5 & 7.6 from Brindley 1970). The curves shown in both figures can be divided into two segments, an upper cone mediated segment and a lower rod mediated region. The shoulder between the two graph segments represents a region where both rod and cone function overlap, although both photoreceptor types are relatively inefficient in this region.

The lookout walked into the wheel house 9 mins prior to the incident from a bright environment. Hence, from the above figures, had the wheel house been totally dark he would have been a long way from complete dark adaptation by the time of the incident. Taking the data shown in the provided figures it is clear that he would have been approximately 50% fully dark adapted had he been in total darkness. However, from the information provided he was not adapting in a dark environment, but was subject to local environmental illumination and back lighting from the deck. Even though there is no direct data on the environmental illumination, the limited evidence argues strongly that his ability to see objects with a small visual angle in a dark field would be seriously compromised from the time he entred the wheel house to the time of the incident. This would be independent of the glasses he was wearing.

4] Conclusion

While it is likely that the glasses contributed to a reduction in the acuity of the look out, the major contributing factor is likely to be insufficient dark adaptation due to the relatively short time in the wheel house and the levels of environmental illumination within it. These factors would have been compounded the fact that the glasses absorbed a minimum of 20% of the environmental illumination when tested from complete darkness.

In light of these findings, greater efforts should be made to regulate light levels in the wheel house at night, and those taking over a watch should be provided with an appropriate period to dark adapt. There should be a maximum permitted level of light in the wheel house during hours of darkness. Further, it is inadvisable that photochromic glasses should be used.

References

G.S. Brindley. Physiology of the Retina and Visual Pathways. Monographs of the Physiological Society. Edward Arnold. London 1970.

D.G. Pitts. Dark adaptation and aging. Journal of the American Optometric Association. 53: 37-41. 1982.

D.M. Stevens. Relationship between dark adaptation and age. Nature 157:376-377. 1946.

1st Dec 2006.

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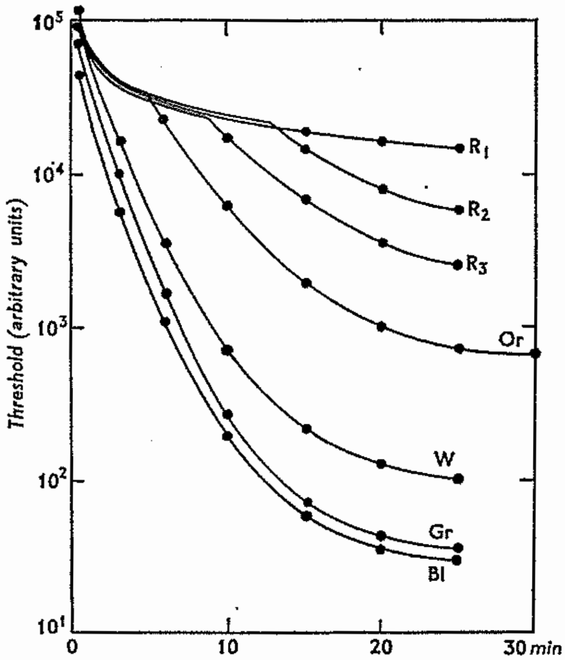

FIG. 7.5. Course of dark-adaptation for 1° circular fields of various colours, placed 5° from the fixation point. Wavebands were isolated by means of filters. B_1 = blue, Gr = green, W = white, Or = orange; R_3, R_2 and R_1 are reds of successively longer wavelength (from Kohlrausch, 1931).

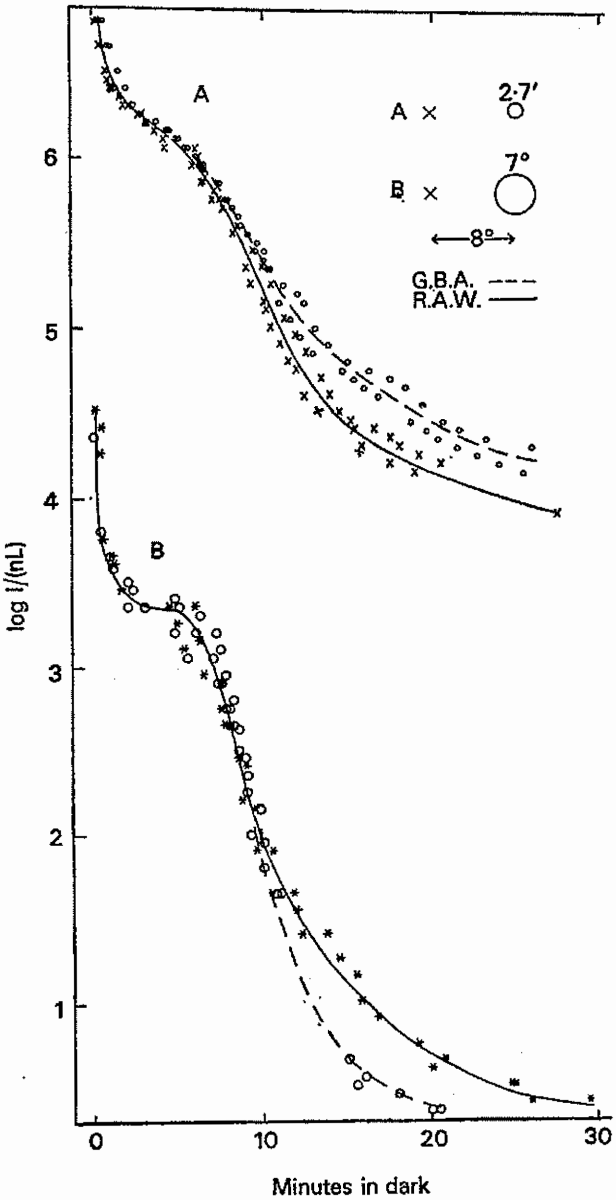

FIG. 7.6. Dark-adaptation curves for large (7°) and small (2·7) fields, 8° from the fixation point (from Arden and Weale, 1954).

Annex 4

Report from QinetiQ:
"Investigation into the likelihood of the *Pride of Bilbao*'s radars detecting a small yacht"

QinetiQ

This document is supplied by QinetiQ for the MAIB under Contract No. SEA00450.

Investigation into the likelihood of the Pride of Bilbao's radars detecting a small yacht.

Steve Luke
QINETIQ/D&TS/SEA/CR0613369
November 2006

Administration page

Customer Information	
Customer reference number	
Project title	Visit to the Pride of Bilbao
Customer Organisation	Marine Accident Investigation Branch
Customer contact	Captain Tony Gill
Contract number	SEA00450
Milestone number	1
Date due	13th October 2006

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Record of changes		
Issue	Date	Detail of Changes
Draft	13th October 2006	-
1st Issue	6th November 2006	Issued after technical review

List of contents

1 Introduction

This short report looks into a number of factors which may have contributed to the sinking of yacht Ouzo in the English Channel over the period 20^{th} to the 21^{st} of August 2006. QinetiQ were tasked by the MAIB to assess the probable radar cross section (RCS) of Ouzo and discuss how this may have contributed to the accident.

The report describes a visit to the Ouzo's sister yacht Pandit to assess its RCS and two visits to the Pride of Bilbao looking at the serviceability of its radars.

There is also a section on yacht RCS and the use of radar reflectors.

Based on yacht Ouzo's estimated RCS and the prevailing conditions at sea during the incident, a prediction of the Pride of Bilbao's probability of detecting the yacht has been produced.

2 Visit to yacht Pandit

On the 11th of September Captain Tony Gill (MAIB), Graeme Batchelor (QinetiQ) and Steve Luke (QinetiQ) visited the Ouzo's sister yacht Pandit in its berth in Gosport. The Pandit is pictured below in figure 1. The Ouzo was thought to be an almost identical vessel to this with the exception of the outboard motor shown on the rear. It is believed by the MAIB that the Ouzo carried a "flat pack" octahedral although it is not know what size or type this was or whether it was being used at the time of the incident.

Figure 1 Sailboat Pandit berthed in its marina.

The purpose of this visit was to estimate the radar cross section (RCS) of the vessel.

- Looking at the photo of Pandit the sides of the vessel are angled away from the vertical. This will reduce the RCS of the boat from the sides.
- Looking directly at the stern will give a larger RCS from the near vertical transom.
- The companionway and adjacent near vertical faces are sloped back; this will form a misshapen corner reflector which will have a small RCS in both aft quarters.
- All around the bow of the vessel it is again angled back and will have a low RCS.
- The yacht is mainly glass reinforced plastic which will reduce the RCS compared to a metallic vessel.

3 Yacht radar cross section

This is a short note on the radar cross section (RCS) of small yachts at X band and the use of radar reflectors that meet ISO8729.

The reflected signal returned from any target when illuminated by a radar is directly proportional to its RCS, i.e. the larger its RCS the stronger the return to the radar. The radar signals generally only travel along the line of site from the radar to any target; and any obscuration from land, other vessels, the sea and the horizon will shadow any target.

It is estimated that the RCS of a small <30' yacht will be in the order of $1m^2$ to $10m^2$ depending upon its aspect angle to the radar – this is demonstrated in figure 2. It is believed that the Pride of Bilbao would have viewed the Ouzo from its port aft quarter. This is at an angle of -135°in figure 1, therefore an estimated RCS value of $1m^2$ has been used to quantify the yacht in the later modelling.

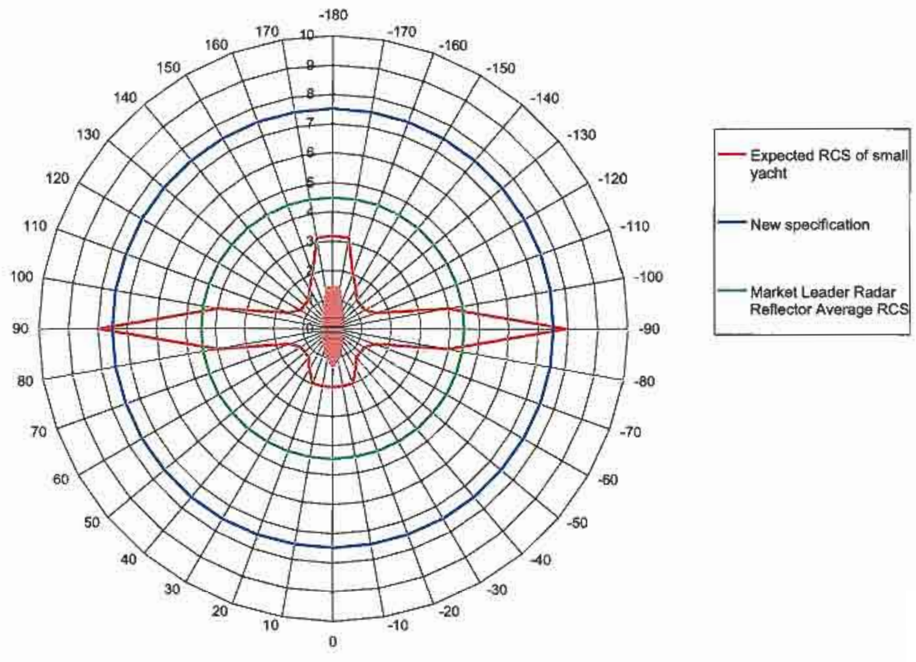

Figure 2 Plot showing expected RCS levels in m^2 against aspect angle for a yacht against expected returns from a radar reflector.

Figure 2 also shows the average RCS of the market leader passive radar reflector and the RCS value which is due to be used for the new radar reflector specification (to replace ISO8729 in the next year or so). This shows that the reflector helps to fill in the low RCS areas of a yacht's cross section. The reflector should be mounted >4m above sea level to help to separate the target from the clutter and masking caused by waves.

Figure 3 shows a photograph of a yacht in profile fitted with a radar reflector; included on the photograph is a description of how radar energy may be reflected from it. It shows that the majority of energy hitting the cabin sides is reflected up and away from the radar and the energy hitting the hull is reflected into the sea, again not back towards the radar. The majority of energy reflected back to the radar in this instance will be from the radar reflector mounted upon the mast.

The mast itself will offer a large RCS, but only when the mast is perfectly vertical will this energy be reflected back to the radar. In nearly all conditions the mast will not be vertical, so the RCS will not be significant.

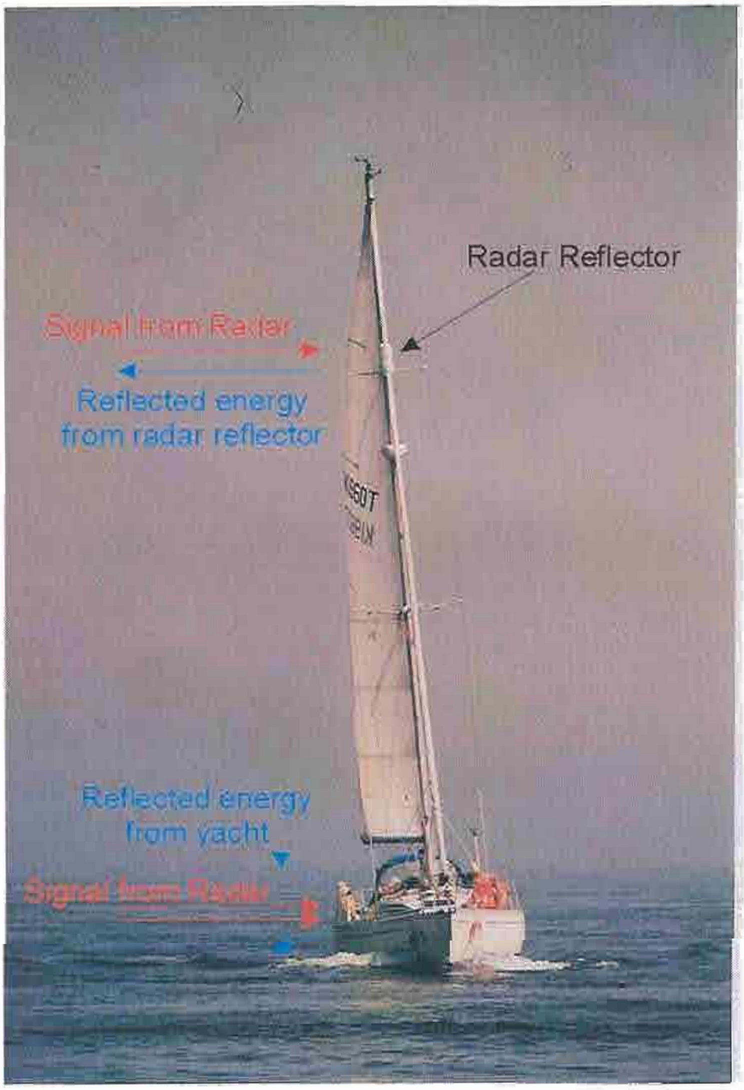

Figure 3 Radar returns from a small yacht

Also, in rougher seas and if there is sufficient wave height, the waves will also shield the main structure of the yacht from radar. This illustrates the importance of fitting a radar reflector in these conditions.

It is understood that the Ouzo carried (but not permanently fitted) a flat pack radar reflector. Figure 4 shows a photograph of a Davis Echomaster flat pack radar reflector which may have been the type carried by the yacht. The Davis Echomaster is one of the best of the flat pack reflectors on the market, although it's performance is still not great [1].

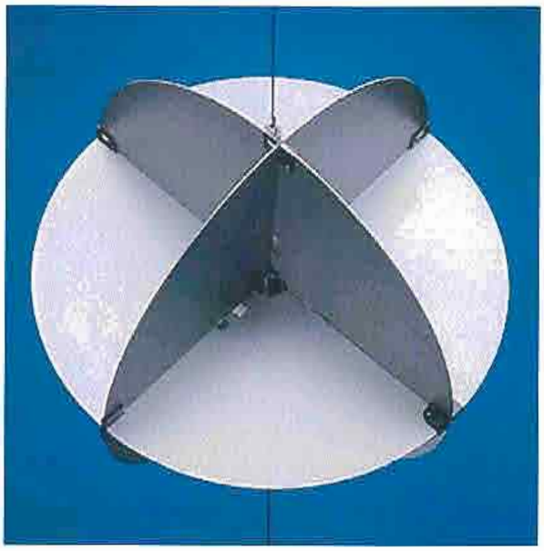

Figure 4 Photograph of a Davis Echomaster radar reflector.

Figure 5 below shows the RCS of a Davis Echomaster radar reflector at X-Band, it shows that the peak RCS is less than 5m² and the average RCS is 1.6m². It can also be seen that there are large nulls well below this average value which describe an RCS of less than 0.5m². It is expected that the RCS of this device at S-Band will be approximately 5 times less than these values. This is shown in the testing carried out by US Sailing [1]; their average RCS figure for this reflector at S-Band was 0.49m² again large nulls will be present in the azimuth RCS pattern. As this target is heeled over the RCS will drop considerably.

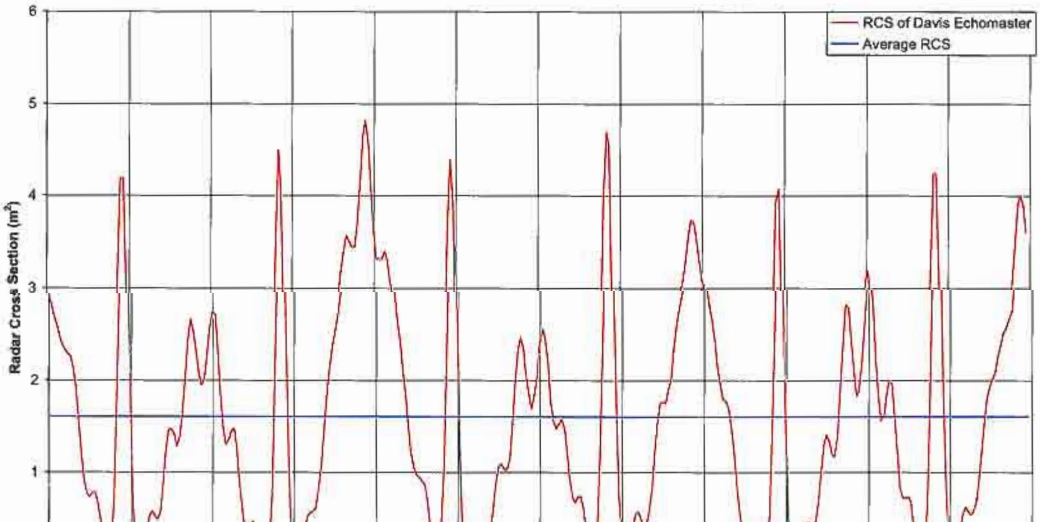

Figure 5 RCS plot of a Davis Echomaster radar reflector at X-Band.

4 Investigation of radars on Pride on Bilbao

Further to the visit to yacht Pandit, QinetiQ were asked to inspect the radars used onboard the P&O Ferry the Pride of Bilbao whilst she was in port (in Portsmouth) on the 14th of September 2006.

The Pride of Bilbao has 3 radar display units controlling 5 scanners in total; these are listed in table 1.

Scanner	Location	Controlled by display
S Band (3.05GHz)	29.8m above sea level on main mast.	Either of the main Bridgemaster E displays in the middle of the bridge.
Primary X Band (9.41GHz)	32m above sea level on main mast	Either of the main Bridgemaster E displays in the middle of the bridge.
Forward X Band scanner (9.41GHz)	16.4m above sea level on bow (below bridge)	Either of the main Bridgemaster E displays in the middle of the bridge.
Forward X-Band docking scanner (9.41GHz)	On the port side of the bridge roof.	Separate Bridgemaster system on the port side of the bridge.
Aft X-Band docking scanner (9.41GHz)	On the aft port corner of the superstructure.	Separate Bridgemaster system on the port side of the bridge.

Table 1 Radar scanner and display unit location.

Figure 6 Photograph of the Pride of Bilbao showing the location of its radar scanners.

During the course of the visit the main S-Band radar was inspected primarily from the left hand main display in the bridge and the main X-Band scanner from the right hand main display unit. The performance monitoring (PM) on both units was viewed and both X and S band displays were compared with one another. This comparison showed no observable differences between long range performance.

The PM for the S-Band system showed all 4 performance rings on the display indicating good performance.

The PM on the X-band system only showed 1 of the 4 expected rings on the display indicating that the performance was degraded. The officer on watch explained that the performance monitoring never worked very well in port due to the high levels of clutter on the radar. The general performance of the X-Band system showed similar features as the S-Band system, therefore it was accepted that the X-Band system was functioning correctly.

The docking radars are not used in the open sea and are not fitted with a performance system and therefore they were not tested.

On the 19th of September 2006 a revisit to the Pride of Bilbao was made with Peter Amess an engineer from Northrop Grumman Sperry Marine (NGSM) who was requested by the MAIB to further investigate the onboard radars. He carried out the same performance monitoring checks as before.

The repeat assessment showed that the S band system was working within specification, but the X band system was not. NGSM recommended that the magnetron be replaced and subsequent to its replacement, performance checks were repeated. These still showed an out of specification performance. The receiver assembly was then identified as a likely cause of the problem and on replacing this, subsequent PM checks showed an acceptable performance

After discussion with NGSM it was agreed that the performance degradation of the X-Band system would reduce its maximum detection range of all targets. However after comparing the S and X band systems it was believed that the degradation in performance was not large [2].

5 Minimum range calculations for Pride of Bilbao

The minimum range of a radar is dependant upon a number of variables these include pulse width, location of radar, elevation beamwidth of scanning antenna, and any system delays.

5.1 Minimum range based on pulse width and system delays

The type of radar system employed on the Pride of Bilbao utilises receiver blanking to suppress the energy contained within the transmit pulse overpowering the receiving circuits. The result is a blind area around the radar because the system cannot receive while transmitting. The radius, or range, of this blind area is determined by the pulse length and system delays designed to give the receiver additional protection.

The theoretical minimum range based on pulse width has been calculated for each of the pulse modes on the radar systems and is shown in table 2.

To quantify the actual minimum range, including the additional system delays and protection, measurements were performed using an S-band Bridgemaster E system based at QinetiQ Funtington. The results are also included in table 2 for all 3 pulse lengths.

Radar Type	Mode	Pulse length (ns)	Theoretical minimum range (m)	Measured minimum range (m) (Funtington radar)
S & X Band	Short Pulse	50	7.6	56
	Medium Pulse	250	37.9	111
	Long Pulse	750	113.6	222

Table 2 Table showing minimum range of the Pride of Bilbao's radars due to pulse width

5.2 Minimum range at sea level based on scanner height and beamwidth

Another factor affecting the performance of radar on ships at sea is the height of the antenna above the sea surface. This coupled with the width of the radiation beam in elevation (height) gives an area close in to the ship where targets are unlikely to be detected.

Table 3 gives the figures for the heights of the radars on the ship and corresponding minimum ranges.

Radar	Height above sea level (m)	Elevation beam width (deg)	Minimum range (m)
S Band	29.8	30	111
Primary X Band	32	24	150
Forward X Band	16.4	24	77

Table 3 Table showing minimum range of the Pride of Bilbao's radars due to scanner location and elevation beamwidth

5.3 Shadowing by superstructure

Shadowing by the superstructure of the vessel will also affect the radar's minimum range. Figure 5 shows the elevation beamwidth of the S-Band radar superimposed on a photograph of the Pride of Bilbao. It can be seen that the superstructure does not shadow this radar in the forward direction which is also true for the port and starboard directions, although it will greatly affect the minimum range in the aft direction.

The primary X-Band scanner is higher on the mast than the S-Band scanner and has a narrower elevation beamwidth; therefore shadowing effects will be reduced compared to the S-Band.

Figure 7 Diagram showing the elevation beamwidth of the S-Band radar overlaid on a photo of the Pride of Bilbao

5.4 Minimum range based on all factors

Table 4 shows the minimum ranges of the three main radars taking into consideration pulse width, location of radar, elevation beamwidth of scanning antenna, and any system delays.

Radar	Mode	Minimum range (m)
S Band	Short Pulse	111
S Band	Medium Pulse	111
S Band	Long Pulse	222
Primary X Band	Short Pulse	150
Primary X Band	Medium Pulse	150
Primary X Band	Long Pulse	222
Forward X Band	Short Pulse	77
Forward X Band	Medium Pulse	111
Forward X Band	Long Pulse	222

Table 4 Expected minimum range for the three main radars on the Pride of Bilbao

6 Predictions of probability of detection

Without knowing the actual RCS of the yacht at the aspect that the Pride of Bilbao would have seen it and the exact sea conditions, it is very difficult to recreate the scenario within a computer model. But using estimations of $1m^2$ for the bare yachts RCS and 5 foot swell for the sea state modelling was carried out to see what may have occurred during the incident. Using the same model the scenario was repeated with a radar reflector fitted to the yacht at a height of 5m, the radar reflector was set to a value of $1m^2$ at S Band and $10m^2$ at X Band.

The predictions were made using QinetiQ's naval electromagnetic environment simulation suite (NEMESiS). NEMESiS is an advanced propagation tool that simulates how microwave energy propagates through the atmosphere and interacts with the terrain.

Table 5 shows the parameters used to model the S-Band radar.

Parameter	S-Band radar	X-Band radar
Peak power (kW)	30	25
Pulse Duration (μs)	0.75	0.75
Transmit gain (dB)	26	30
Receive gain (dB)	26	30
Noise (W/Hz)	2.006e-20	3.179e-20
Loss (dB)	5	5
Polarisation	HH	HH
Azi Bw (deg)	2	1.3
Radar	Bridgemaster E type	Bridgemaster E type
CFAR (constant false alarm rate)	0.0001	0.0001
Antenna height (m)	30	32

Table 5 Modelled radar parameters

The yacht was modelled with and without a radar reflector. For the bare yacht an RCS of $1m^2$ at a height of 1m above sea level was selected to account for returns from the hull and cabin. For the scenario with a radar reflector fitted the RCS was set to a value of $1m^2$ at S Band and $10m^2$ at X Band at 5m above sea level, which is typical for radar reflector that meets ISO8729 [3].

The following parameters were used to model the target and the seas state for this scenario.

Parameter	Without a radar reflector	With a radar reflector fitted
Target RCS	$1m^2$	$1m^2$ S-Band $10m^2$ X-Band
Target Height	1m	5m
Swerling	1	1
Wind speed (m/s)	8.2	8.2
Land clutter	Necaps	Necaps
Sea Clutter	GIT [4]	GIT [4]

Table 6 Modelled target and scenario parameters

The Naval Environmental Clutter, Attenuation and Propagation Specification (NECAPS) describes a 5ft swell as a moderate to rough sea state, which is created by a wind speed of approximately 8.2m/s. This parameter has been used to simulate the 5ft swell in the model.

6.1 Predictions of probability of detection of a yacht at S-Band

Figure 8 show the probability of detecting a small yacht with and without a radar reflector when using the S Band radar fitted to the Pride of Bilbao.

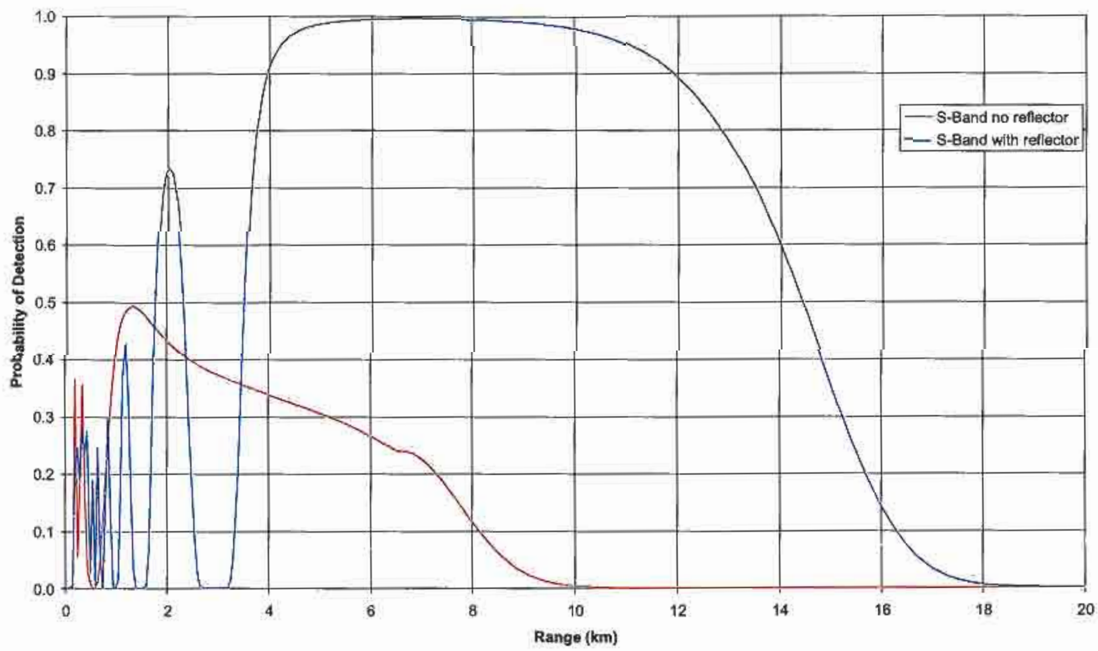

Figure 8 Probability of Pride of Bilbao's S-Band radar being able to detect a yacht with and without a radar reflector.

Without a radar reflector the probability of detection is only 50% at the peak at a range of 1.4km, making it very unlikely that enough high returns will occur in sequence to make a good detection. With a radar reflector fitted there is a window with a probability of detection at 70% at 2km and then from 4-12km there is a 100% chance of detection. The lobing structure shown at short ranges for both cases will be due to both multipath and clutter effects. The actual probability of detection with a radar reflector fitted will be a combination of the yacht and the radar reflector plot shown, some the large nulls visible will be filled by the returns of the yacht.

6.2 Predictions of probability of detection of a yacht at X-Band

Figure 9 show the probability of detecting a small yacht with and without a radar reflector when using the X Band radar fitted to the Pride of Bilbao.

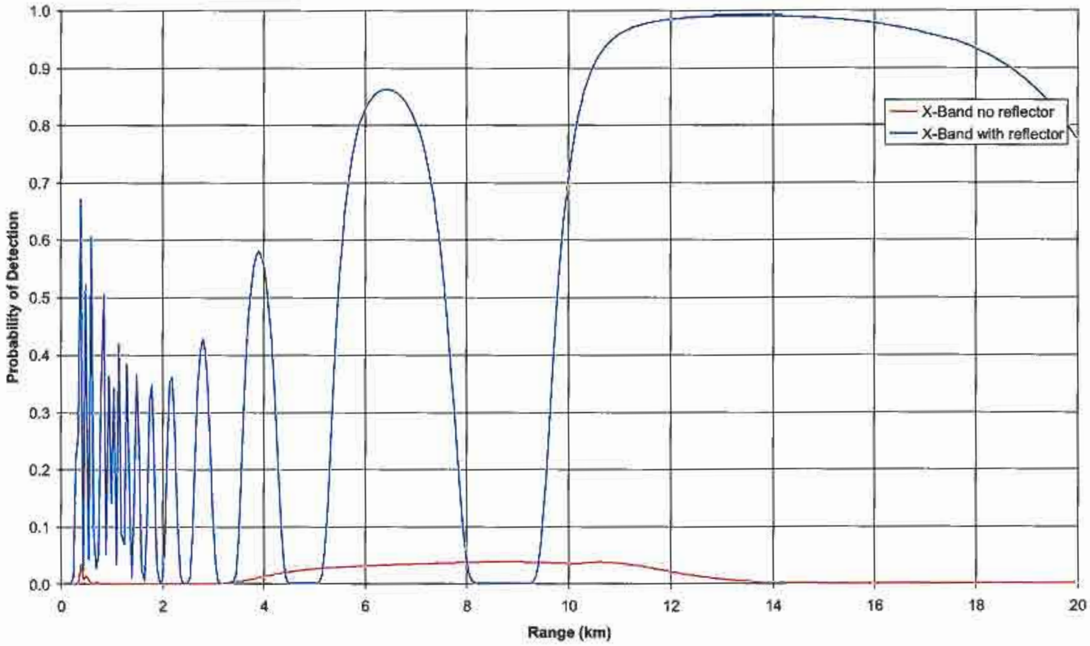

Figure 9 Probability of Pride of Bilbao's X-Band radar being able to detect a yacht with and without a radar reflector.

Without a radar reflector the probability of detection is very low (less than 5% chance), making it extremely unlikely that any detection will occur. With a radar reflector fitted there is a window with a probability of detection at 70% at 5-7km and then from 10-19km there is a >90% chance of detection. The lobing structure shown at short and medium ranges for the radar reflector case will be due to both multipath and clutter effects.

7 Conclusions

It is understood that the Ouzo carried (but not permanently fitted) a flat pack radar reflector. QinetiQ Funtington is the UK's main type approval test house for radar reflectors and has tested many varieties of these types of reflectors, and in our experience these types of reflectors only offer poor performance. It is unlikely that even if this reflector was raised on the mast that it would have made much difference to the RCS of the yacht.

It also understood that the accident occurred in seas with a wave height of 4 or 5 feet, this would have shielded the main structure of the yacht from any other vessel's radar. This has been backed up by the modelling work which has been carried out.

Looking at the modelled data it is unlikely that the Pride of Bilbao would have been able to separate the Ouzo from the clutter. The best chance for the detection of the yacht would have occurred at 1.4km but this still only shows a 50% probability of detection.

Had the yacht been fitted with a radar reflector that meets ISO8729 and has an RCS of $10m^2$ in X-Band and $1m^2$ at S-Band it is likely that the Pride of Bilbao would have been able to track the yacht.

8 Recommendations

It is recommended that all small vessels fit a radar reflector that meets the requirements of ISO8729[3].

9 References

[1] http://www.ussailing.org/safety/Studies/radar_reflector_test.htm - Radar Reflector Testing, 1995 by Jim Corenman, Chuck Hawley, Dick Honey and Stan Honey (US Sailing)

[2] Product Service Report 711986 from Peter Amess, Northrop Gruman Sperry Marine Ltd, dated 19/9/06

[3] BS EN ISO 8729:1999 - Ships and marine technology. Marine radar reflectors

[4] Method for modelling sea surface clutter in complicated propagation environments. IEE proceedings. Volume 137, Issue 2, April 1990 - GD Dockery

10 Acknowledgements

The author wishes to thank; Suzy Moldau and James Branson from the Maritime Radar Techniques and Environment group at Portsdown Technology Park for their assistance in the NEMESiS modelling work, and Seb Di Laura and Paul Tribe from the Radar Signatures & EME group for their assistance in estimating the RCS of the yacht Ouzo.

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Abstract This short report looks into a number of factors which may have contributed to the sinking of yacht Ouzo in the English Channel over the period 20th to the 21st of August 2006. QinetiQ were tasked by the MAIB to assess the probable radar cross section (RCS) of Ouzo and discuss how this may have contributed to the accident. The report describes a visit to the Ouzo's sister yacht Pandit to assess its RCS and two visits to the Pride of Bilbao looking at the serviceability of its radars. There is also a section on yacht RCS and the use of radar reflectors.			
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Extracts from the Preliminary Medical Report
by Dr F StC Golden OBE, PhD MB, BCh.

Extracts from the Preliminary Medical Report

By
Dr F StC Golden OBE, PhD MB, BCh.

(Relevant biographical details of author, together with a list of the documentary evidence studied in the formulation of this report, is given at the Annex to this report)

The Yacht "OUZO"

INTRODUCTORY NARRATIVE BASED ON AVAILABLE FACTUAL DATA

1. Having departed Bembridge, IOW, at or about 2030 on the 20th August 2006, the yacht Ouzo sank in the English Channel to the South of St Catherine's Point, Isle of Wight, in the early morning of the 21st, August 2006.

2. The three occupants of the yacht were:

    a. **James Meaby,** (age 36; height-183cm (6.0ft); weight –78kg (172lbs). Body Mass Index (BMI) 23.3 (i.e. within normal range for his age group, viz. <25).
    b. **Rupert Saunders**, (age 36; height 183cm(6.0ft); weight – 80kg (12.8lbs) BMI 23.9 (i.e. within normal range).
    c. **Jason Downer**, (age 35; height – 173cm (5.8ft); weight 77kg (170lbs). BMI 25.7 (marginally overweight).

3. The bodies of the three crew members were subsequently located as follows:

    a. **James Meaby**: located about 10 miles due South of the Nab tower on the 22.08.06, by the fishing boat MALIKI. The Bembridge lifeboat subsequently recovered the body at about 1230. The LJ appeared to be fully inflated
    b. **Rupert Saunders**: located to the South of Ventnor, Isle of Wight, about 9 miles to the West of where James Meaby was located, by the Lee-on-the-Solent Coast Guard helicopter on the 23.08.06 at 1900 and recovered a short while later by the Yarmouth lifeboat. The LJ appeared to be fully inflated.
    c. **Jason Downer**: located in close proximity (approx 400 yards) to the body of Rupert Saunders, and recovered by the Yarmouth Lifeboat. The lifejacket, again, appeared to be fully inflated.

4. Prevailing environmental conditions:
    a. Visibility: Good but overcast and very dark night. Wind - WSW, force 4-5.
    b. Sea state – slight to moderate; small waves (approximately 4-5 ft high), occasional breaking crests.

c. High water @ 22.19. Wind with tide until 22.19, and thereafter against tide.
d. Sea Temperature in vicinity of presumed sinking = 18.8°C.

:

5. Clothing worn by victims**:**

a. James Meaby

i. Light weight 'T-shirt'
ii. Knee length shorts
iii. Short woollen socks
iv. Full-length, lined, waterproof sailing trousers (manufacturer "Henri Lloyd"). Zip & Velcro fly, elasticated waist, and shoulder straps ("braces"). Velcro tightening straps at ankles.
v. Wellington boots (sailing design)
vi. Long sleeved, "Helly Hansen" sailing jacket with thermal lining, draw string waist and full-length zip & Velcro front opening.
vii. Waterproof, red, sailing outer jacket (manufacturer "Henri Lloyd"), with elasticated cuffs, integral adjustable hood and full-length zip & Velcro front opening. (PM photograph No.06-15889-1-1-001 in unnumbered Exhibit (working copy E208); and in PM photograph No.06-15887-14-1-029 in Exhibit No JFT/C/2/1.)
viii. Fingerless sailing gloves
ix. "Crewfit", 150Newton, lifejacket with shoulder and waist straps, gas inflation (manual activation). Manufacturer – Crewsaver.

b. Rupert Saunders

i. Ankle socks under short Wellington boots
ii. Knee length cotton trousers
iii. Neoprene left knee brace secured by Velcro strapping, extending from upper third of calf to mid thigh.
iv. Short sleeved rugby shirt
v. Long sleeved fleece jacket
vi. Full length yellow, waterproof, "MUSTO" sailing trousers, with 'Velcro' securing strap at ankles, elasticated waist, and shoulder straps ("braces").
vii. Waterproof, black, "MUSTO" yachting jacket with zip and Velcro fastenings at wrists and full-length front opening. Integral, lightweight yellow waterproof hood. (PM photograph 06-15887-14-1-009 in Exhibit No JFT/C/2/1; and in PM photograph No. 06-15887-5-1-001)
viii. "Crewfit", 150Newton, lifejacket with shoulder and waist straps, gas inflation (automatic activation). Manufacturer – Crewsaver.

c. **Jason Downer**

   i. Knee length cotton trousers
   ii. Long sleeved (warm) round necked shirt
   iii. Long sleeved, "Helly Hansen" woollen lined, windcheater, with integral hood. Draw string waist, elasticated wrists, and full-length zip & Velcro front opening.
   iv. Lined "Gore-Tex" sailing trousers; each trouser leg had a 3/4 length lateral split with zip & Velcro fastening. Stud securing at ankles. Draw string waist, and shoulder straps ("braces").
   v. Waterproof, black with lateral white line trim to outer sleeve, "MUSTO" yachting jacket with zip and Velcro fastenings at wrists and full-length front opening. Integral, lightweight waterproof hood. (PM photograph 06-15887-14-1-022 in Exhibit No JFT/C/2/1; and PM photograph 06-15887-4-1-001 in Exhibit No E236)
   vi. Lightweight "Timberland" sailing shoes
   vii. Fingerless sailing gloves.
   viii. "Crewfit", 150Newton, lifejacket with shoulder and waist straps, gas inflation (manual activation). Manufacturer – Crewsaver.

6. No overt damage to clothing was noticed at time of Autopsy.

7. Cause of death (as reported by the Dr Purdue, Home Office Pathologist).
   a. James Meaby – "…the combined effects of hypothermia and drowning".
   b. Rupert Saunders –"….drowning" but post mortem autolysis made it impossible to state definitely that he did indeed drown.
   c. Jason Downer - –"….drowning" but post mortem autolysis made it impossible to state definitely that he did indeed drown".

8. There was no post mortem evidence of any of the three victims having suffered an incapacitating traumatic injury or illness.

<u>Immersion Survival Phase</u>

9. It is to be expected that once in the water, the victims would inflate their lifejackets (LJ), if not already activated. The cold water (18°C) permeating beneath their outer clothing (via wrist, ankle, & neck apertures) would cause a sudden cooling of the skin, resulting in a mild to moderate 'cold shock' response – unless the individual was already habituated to immersion in water at that or a lower temperature. Given the environmental conditions and their general state of health, this cold shock response should not necessarily cause them any difficulty, other than intensifying the psychological shock associated with their predicament.

10. Once they recovered from the cold shock, after approximately 3 minutes, it is probable that they would then settle down and prepare themselves for the long-term survival ordeal. This will be more successful if they have received prior survival training, i.e. acquired knowledge of the correct actions to take in such an eventuality.

11. Survival time would be dependant on a number of interacting factors, viz.:
    a. Water temperature
    b. Sea state
    c. Body insulation (intrinsic; i.e. body fat; and extrinsic, i.e. clothing worn).
    d. Buoyancy and airway protection, particularly in non-swimmers.
    e. Personal characteristics, e.g. gender, size, and fitness
    f. Heat production, i.e. exercise, shivering.
    g. Body posture.
    h. Seasickness, or the presence of other debilitating factors such as intoxication, severe injury, etc.
    i. Mental state.

12. *Hypothermia.* A sea temperature of 18°C, while 'cold' from a physiological viewpoint, is not regarded as so severe as to cause a significant fall in the body temperature in a short time, i.e. < 6 hours. In well nourished, fit, adult males, especially when dressed as these victims were, it would be surprising if they became significantly hypothermic in less than 12 hours. They would, however, eventually become hypothermic, and if their airways were not adequately protected from water aspiration, would die from drowning.

13. *Sea state.* When floating passively in water, as one could do when wearing a correctly fitting, fully inflated, LJ, the mouth to water distance is normally maintained at a distance of >12cm, or more[1]. This distance is sufficient in calm water to protect the airway from being compromised by water splash. However, in an open seaway, the natural flotation posture for a relaxed individual, wearing a LJ, is to face the oncoming wave. If the waves are cresting, then a number will break over the front of the LJ and the face of the wearer. To avoid water aspiration in such circumstances, it will be necessary to breath-hold at the appropriate time. As this is a voluntary action, there would be a requirement for the immersed victim to be fully conscious to avoid aspiration.

14. In a sea state, in which wave frequency is high, and as a consequence frequent breath holding is required (possibly with every wave), it becomes difficult to breathe normally and effectively. In such conditions the victim very quickly learns, naturally, to turn his back to the waves; this makes breathing very much more comfortable and effective. However, to maintain this attitude

[1]The SOLAS Convention of 1983 (Regulation 32), states that an approved lifejacket (LJ) should be capable of lifting the mouth of an unconscious person not less than 120mm clear of the water with the body inclined backwards at an angle of 20° and not more that 50° from the vertical position. A LJ should also be capable of turning the body of an unconscious body in the water from any position to one in which the mouth is clear of the water in not more than 5 seconds.

relative to wave direction, it will be necessary for the victim to make appropriate muscular actions, e.g.. arm paddling. But when body temperature falls by >2°C (by definition the onset of hypothermia), the peripheral muscle temperatures will tend to be in the region of 28°C or below. At these temperatures, coordinated muscular activity increasingly becomes impaired and eventually ceases. The hypothermic victim will then be turned (by the wave) to face the oncoming wave, start aspirating water and drown – i.e. before death from hypothermia per se, is likely to occur (deep body temperature of 24-26°C).

15. Given the prevailing sea state conditions in this incident (viz. slight to moderate; small waves, approximately 4-5 ft high, with occasional breaking crests), the wave splash threat should not have constituted a serious survival challenge to fit men wearing fully inflated lifejackets. Prior to their eventual loss of consciousness from hypothermia, the greatest threat from wave splash would have occurred in the earlier part of their ordeal, i.e. prior to 22.19, when the tide was against the sea - assuming the incident had occurred in that period. That threat would have occurred when they should have been at their fittest and therefore more capable of defending themselves from the waves.

16. The probable sequence of events, for someone with effective buoyancy and immersed in a moderate sea state in water at 18°C, is as follows: a brief initial cold shock response followed by a short burst of shivering, which would cease almost immediately as the skin temperature equilibrated with the water temperature beneath the clothing. As body heat starts to flow down the thermal gradient between deep body (37°C) and the sea (18°C), reflex shivering will commence in an attempt to defend deep body temperature. In water at 18°C, such shivering would occur in short intermittent bursts initially but as the exposure time and body cooling progressed, the shivering would intensify and eventually become continuous.

17. Given the general state of nutrition, their BMI, and apparent physical health of the victims in this case, together with the thermal properties of their clothing, their overall rate of body heat loss would not be very high. It is probable therefore, that the time interval between immersion and the onset of this steady state of shivering would be in the order of 2-3 hours in someone floating passively. However, the physical activity undertaken in maintaining ones back to the waves, would generate sufficient body heat to counter the relatively slow fall in body temperature and thus extend that estimate of 2-3hours (to the onset of continuous shivering) by another hour[2].

18. *Lifejackets:* The life jackets the Ouzo crew were wearing had 150 Newtons (34lbs) buoyancy. This level of buoyancy was adequate for their body mass and should therefore have been sufficient to meet the Solas Regulations for approved lifejackets for adults.

[2] That estimate would be longer if the victims were wearing clothing with watertight integrity, which would prevent the flushing of water beneath the clothing associated with movement.

19. When testing lifejackets to meet the approved requirements, the manufacturer's test conditions are usually benign, with the LJs securely fastened to the body of the wearer – often to a naked body. (This test procedure is permissible under the regulation). Unfortunately, in real life usage, the waist fastening is not always as tight as it could, and should, be, particularly when worn over bulky clothing. With the exclusion of air from the clothing of a submerged body, the clothing will loose some of its bulk resulting in a loosening of the waist straps. As a consequence, in a seaway, with the vertical bobbing action of the body floating at an angle of between 20° – 50°, the lifejacket tends to ride up on the body. This will eventually result in the body adopting a more vertical attitude (>50°), which in turn will reduce the benefit of the added buoyancy that a correctly fitting LJ provides. As a result, the airway becomes more easily compromised by the associated decrease in the mouth to water distance.

20. Should the body become only loosely attached to the LJ, it will tend to float loosely around the neck and move independently of the bobbing body. If rescue is not achieved before consciousness becomes impaired through hypothermia, the victim will drown long before death from hypothermia can expected. Even in normothermic survivors, the difficulty in having to continually maintain ones airway clear of the small high frequency wavelets lapping around the mouth, inside the collar of a poorly fitting LJ, is extremely tiring and difficult. The associated effort to consciously control ones breathing at a comfortable level eventually results in water aspiration and drowning. This is likely to occur much more quickly in those not at ease in the water, such as poor swimmers. (It is understood that the three victims in this case were competent swimmers)[3].

21. To overcome this potential problem, many lifejackets (e.g. RN, RNLI, Helicopter Aircrew, etc.) are designed both with a relatively tight fitting inflatable collar, to support the head of an unconscious victim, and fitted with 'crotch straps', to ensure that the waistband does not rise up the body. Crotch straps are available for the "Crewfit 150N" jackets but they have to be purchased as an optional extra. Regrettably, the Crewfit 150N jackets worn by the victims in this incident did not have this extra fitment.

22. The accounts of the rescuers of the flotation characteristics of the three victims in this case, quite clearly describe inadequately secured LJs in all three, although that of James Meaby, at least, appears to have been partially functioning as designed, i.e. the lobes were supporting his body. However, it would appear that the collar was not supporting his head out of the water resulting in his mouth being immersed.

Predicted Survival Times

23. Assuming that the victims were not trapped underwater for a period that could result in early aspiration leading to drowning, and all three were fully conscious on water entry, survival time would be dependant of the factors listed at paragraph 11 above.

[3] Personal communication Capt G Inseal MAIB

24. Given the available knowledge relating to water temperature, sea state, lifejackets used, clothing worn and nutritional state of the victims, their predicted survival times should have been in the region of 12 – 15 hours (plus?). However, if the LJs were not secured to the body correctly, this estimate would have to be revised downwards by a significant factor (3-6 hours).

25. Post mortem evidence demonstrated that all 3 victims died from drowning. In two of the three victims (Rupert Saunders & Jason Downer) there is no autopsy evidence to suggest that this drowning did not occur early in their "survival" ordeal; however, there is evidence that the third victim (James Meaby), had been suffering from hypothermia for some significant time prior to drowning, and given all the factors it is reasonable to deduce that he could have survived for a period of 12 –18 hours before he eventually drowned. However, given the inadequacies of his LJ a more accurate prediction would be in the lower region of that range, viz. approximately 12 hours.

CONCLUSIONS

26. It is probable that James Meaby survived the initial incident that caused the yacht "Ouzo" to founder and remained alive, floating in a survival mode, for a period in the region of at least 12 hours.
27. It is not possible to deduce how long the other two members of the crew, viz. Rupert Saunders and Jason Downer, could have survived after initial water entry before succumbing to drowning They would have received little beneficial support from their poorly fitting LJs once consciousness became impaired, but given the relatively benign environmental conditions they should have been capable of surviving at least 3 hours if they had been fully conscious from the outset of their immersion ordeal.

F StC Golden 27th November 2006
(Consultant in Environmental Medicine and Applied Physiology)

Annex to Medical Report
by Dr F STC Golden
dated 28.11.06

Relevant biographical details of author

1. I am a fully registered medical practitioner with higher professional qualifications both in Aviation Medicine and Applied Physiology with a special interest in Environmental (Thermal & Survival) Medicine. I joined the Royal Navy as a Surgeon Lieutenant in 1963 and retired in the rank of Surgeon Rear Admiral in 1993. The subject of my PhD thesis, taken at the University of Leeds in 1979, was related to the field of Immersion Hypothermia. During the major part of my 30 years service in the Royal Navy I worked closely with the subject of Survival at Sea and founded the Department of Survival Medicine at the Institute of Naval Medicine, Gosport, Hants. The department was responsible for providing specialist advice to the Royal Navy/Royal Marines and other interested bodies, both national and international, on the physiological aspects of survival in adverse thermal environments. Such advice was based on many years' practical experience and research in environmental physiology and associated topics. Some of that research led to the development of much of the current Royal Navy Life Saving Equipment.

2. My experience and expertise in the area of Survival at Sea resulted in my appointment to the UK delegation to IMO - and as chairman of the Cold Water Survival Working Party - involved in the preparation of the documentation for the 1974 SOLAS Convention. I was also a member of the small working party convened by the DoT (Marine Div.) in 1975, to draw up the training syllabus for the statutory Survival at Sea course and the illustrated instruction booklet. I was also, and still am, frequently consulted by a variety of national and international organisations on matters related to Survival at Sea.

3. I have over 50 publications in the open scientific literature, including chapters in medical textbooks on this and related topics. I am also frequently invited to speak at international meetings and conferences on the subject and, together with a colleague, have recently published a book on the medical aspects of survival at sea ("*Essentials of Sea Survival*". Authors: Golden & Tipton. Pub. Human Kinetics, Champaign, Illinois, USA. 2000. ISBN: 0-7360-0215-4).

4. I am currently working as a freelance Consultant in Human Applied Physiology and have an appointment as an honorary lecturer in Applied Physiology to University of Portsmouth.

Documentary Evidence studied

The following is the list of documentation studied to ascertain the facts, where they are known, on which my opinions were formed.

1. Statement of Geoffrey Victor Attrill, Deputy Second Coxswain of the RNLI Bembridge Lifeboat, dated 10/10/06.
2. Statement of Mark Andrew Smith, full time mechanic of the Yarmouth, Isle of Wight RNLI Lifeboat, dated 10/10/06.
3. Statement by PS Tina Lowe, Detective Sergeant, Hampshire Constabulary, dated 04/09/06.
4. Photographic evidence by DC 2322 Harkin, Exhibit Reference CH/UMS/03, numbers 1-44, of bodies found at sea on the 23/08/06
5. Photographic Evidence, dated 22/08/06. Socrates No.06/15889/1/1/ 001 to 013.
6. Photographic Evidence, dated 25/08/06. SSMS No.06/15887/3/1/ 001 to 033.
7. Photographic Evidence, dated 25/08/06. SSMS No.06/15887/4/1/ 001 to 008.
8. Photographic Evidence, dated 25/08/06. SSMS No.06/15887/14/1/ 001 to 042.
9. Photographic Evidence, dated 25/08/06. SSMS No.06/15887/5/1/ 001 to 008.
10. Photographic Evidence, dated 27/09/06. SSMS No.06/15887/27/1/ 001 to 007.
11. Photographic Evidence, dated 27/09/06. SSMS No.06/15887/27/1/ 001 to 006
12. Autopsy reports on James R Meaby, Rupert CW Saunders, and Jason Downer by Dr BN Purdue, Home Office Pathologist, dated 25 September 2006.

Annex 6

P&O Ferries Fleet Management Directives and Circulars

To: Fleet Managers
North Sea/Short Sea/Irish Sea

From: Fleet & Ports Director

Date: 16 January 2007

FD: **02/07**
Circulation: All deck department

Keeping a proper lookout at night

Background
Ensuring that night vision is not impaired by ambient light level or deterioration in an individual's night vision is critical to safe navigation.
It has been determined that it may take up to 30 minutes for night vision to fully recover from exposure to bright light (e.g. in accommodation spaces or at the chart table) and that at least 10 minutes should be allowed for an individual's eyesight to adjust for night vision.
Some types of glasses with photochromic lenses have been discovered to reduce night vision by up to 20%.

Instruction
The officer of the watch is to ensure that the following is complied with on passage and during preparation for departure: -

(1) All chart table (and other) blackout curtains are to be closed during hours of darkness,
(2) All chart table lights are to be dimmed to the minimum practicable level of lighting,
(3) Lookout duties are not to be handed over to another individual without 10 minutes being allowed for the on-coming lookout's eyesight to adjust to night vision, and
(4) The watch is not to be handed over without 10 minutes being allowed for the relieving officer's eyes to adjust to night vision.
(5) If deck lighting such as funnel floodlights or helicopter deck landing lights are interfering with visibility forward or aft, these should be turned off. If light is emanating from forward windows below the bridge which is interfering with visibility, these should be extinguished or blinds drawn to prevent this.

Masters and all bridge personnel are to assist with and monitor compliance with these requirements.

Guidance
Bridge personnel who wear glasses should be aware that a loss of up to 20% night vision may occur if photochromic glasses are worn. Clear glasses should be worn when keeping lookout at night (in the same way as clear glasses should be worn when driving a car at night).

Masters should review lookout routines to ensure that 10 minutes eyesight adjustment takes place prior to handover. Fire round frequency is to be maintained, but routines may be adjusted to reduce the number of changes between lookout and fire round duties during a watch period.

The officer of the watch should ensure continuity of an effective lookout whenever night vision of the lookout is temporarily impaired by exposure to light.

Fleet Regulation 07.4.022 will be amended to include these instructions in due course.

J. P. Garner.

RSR/jw/20.03

To: Fleet Managers
North Sea/Short Sea/Irish Sea

From: Fleet & Ports Director

Date: 16 January 2007

FD: **03/07**
Circulation: All deck officers

Radar operating procedures for optimal performance

Background
It has long been accepted good practice to regularly switch between auto and manual clutter controls and radar range scales to ensure optimal performance in reduced visibility.
Very small craft may not be visible by eye at night (even in good visibility) or in sea states above state 4 (moderate) due to the low height and low power of navigation lights. They may present a poor radar target due to the size of the craft, the material of construction and effectiveness of any radar reflector (if fitted). In these circumstances variation of the radar clutter control may be the only way to assist detection of the craft.

Instruction
The officer of the watch is to periodically switch between automatic and manual clutter control so as to reduce rain and sea clutter suppression and thereby assist detection of small and/or poorly lit craft. This is to be carried out on the operational range and a lower range.
This instruction is to be followed at night in all visibilities and as appropriate during any period of reduced visibility.

Masters and deck officers are to prompt and monitor compliance with this requirement.

Guidance
It should be remembered that both 3cm and 10cm wavelength radar displays should be observed so as to capture active racon or small craft enhancing transmissions which, depending on type, may transmit on either 3cm or 10cm wavelength.

Consideration should be given to the likely density of small vessel traffic for instance at the entrances to popular sailing ports. This instruction should be carried out more frequently in possible high density areas such as arrival / departure from port and when close to shore.

Fleet Regulation 07.4.022 will be amended to include this instruction in due course.

J. P. Garner.

RSR/jw/20.03

To: Fleet Managers
North Sea/Short Sea/Irish Sea

From: Fleet & Ports Director

Date: 16 January 2007

FD: **04/07**
Circulation: All deck department

Calling the Master

Background
Fleet Regulation 07.4.022 (Section 1.1.1) includes many circumstances in which the officer should inform the master. The listed circumstances are not exhaustive, and the OOW must use his judgement and experience to decide whether it is necessary to call the master. However, as a general rule, if an OOW considers that a situation might require a call to the master, then a call should be made. No officer or lookout shall be criticised for calling the master if in doubt or where he is concerned about the navigation or safety situation.

Instruction
The officer of the watch must not hesitate to call the master immediately
(1) in any potentially hazardous circumstances or if in any doubt whatsoever about the safety of the ship for any reason **or the safety of other craft or persons.**
(2) in event of any near miss situation including any potential swamping of a small craft.

A lookout should also call the master if he has serious doubts about the safety of the ship or another craft but is unable to persuade the OOW of the need to do so.

The master and/or officer of the watch must take positive action to ensure the safety of others if ever in any doubt whatsoever about a near miss situation or potential swamping of a small craft. Such action must positively verify the safety of others. Additionally the officer of the watch must not hesitate to take positive action before the arrival of the master on the bridge.

Guidance
The circumstances in which a close quarters situation becomes a "near miss" involving a small craft are difficult to define because it depends on all the facts prevailing at the time (e.g. day or night, visibility, sea state, relative courses, CPA etc). However, if there is any doubt in the minds of the bridge team as to whether a "near miss" has occurred or if a small vessel has been endangered due to the wash / wake of the vessel then they must err on the side of caution and call the master immediately.

Fleet Regulations will be amended in due course.

J.P. Garner.

RSR/jw/20.03

To: Fleet Managers
North Sea/Short Sea/Irish Sea

From: Fleet & Ports Director

Date: 16 January 2007

FD: **05/07**
Circulation: All deck officers

Familiarisation with bridge equipment and bridge team members

Background
A high standard of watch keeping requires thorough knowledge of bridge equipment and its operation, together with well developed teamwork.
Familiarisation procedures laid out in Fleet Regulations (06.3.008) include Bridge Equipment and its uses (STCW A –1/14), Steering Systems, Engine / Propeller Controls, and Navigational Aids and other bridge equipment (STCW A – V/2).

Instruction
Masters are to ensure that familiarisation procedures for deck officers include the following;

(1) steering controls and system operation in all modes of steering
(2) operation and limitation of any auto pilot course adjustment and rate of turn controls
(3) operation and any limitation in use of main engine controls
(4) the manoeuvring characteristics and stopping distances of the vessel
(5) so far as is practicable a new officer should meet the ratings who are detailed to form his bridge team in advance of standing a watch. The purpose of this meeting is to assist teamwork through the familiarisation and bonding which results from awareness of background and professional experience.

Guidance
It is particularly important that officers who are new to a vessel/class of vessel do not assume that equipment operates in the same manner as that they have previously experienced. Complete understanding of bridge equipment operation should be positively verified before completion of the officer's familiarisation.

Fleet Regulations will be amended in due course.

J. P. Garner

RSR/jw/20.03

To: Fleet Managers
North Sea/Short Sea/Irish Sea

From: Fleet & Ports Director

Date: 16 January 2007

FC: **04/07**
Circulation: All deck officers

Maintaining situational awareness whilst taking avoiding action

Background
The importance of the officer of the watch having situational awareness is critical to the safe navigation of the vessel and the safety of persons both on board his own vessel and other vessels in the vicinity. As a basic rule, the OOW and lookout should keep a good lookout so that any potential close quarter situation is identified and early action is taken to avoid such situation. Where a close quarter situation appears unavoidable, the master should always be informed (see FR .07.4.022).

It is appreciated that despite the best efforts of the bridge team, a close quarter situation can arise unexpectedly and at short notice, particularly with very small craft and floating objects such as semi-submerged containers. As far as possible, the OOW should engage hand steering in advance of a close quarter situation developing, or as soon as such a situation is perceived, to give the OOW the broadest possible range of options for taking avoiding action.

Guidance
Where immediate manoeuvring is required the officer of the watch should engage hand steering with a rating on the wheel at the earliest opportunity so that he is free to move about the bridge and maintain full awareness of the situation.
Attempting to take action in an alternative steering mode is likely to require the officer to remain at that control location, thereby severely limiting his ability to maintain full situational awareness. Although the lookout may be free to move about the bridge he will not be able to achieve full awareness of the situation, hence the guidance that the officer of the watch should engage hand steering with a rating on the wheel at the earliest opportunity. As soon as is practicable the officer of the watch should call a lookout to the bridge.

J. P. Garner

RSR/jw/20.04